BASIC TELEVISION

VAN VALKENBURGH
NOOGER & NEVILLE
INC.

PARTS
1, 2 & 3
COMPLETE

TECHNICAL
PRESS

BASIC TELEVISION

Part I

A Basic Training Manual developed by

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working in conjunction with
the Editorial and Art Staff of the Publishers.

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PREFACE

The aim of this Series on *BASIC TELEVISION* is to explain in simple language the physical principles which make television possible and the way in which a typical television system works—from the generation of the signal in the TV camera to the final presentation of the picture on the screen by your own fireside. The Series is based on the two TV systems working in Great Britain today—the very-high frequency (VHF) one working on 405 lines per picture and the ultra-high frequency (UHF) one working on 625 lines per picture. The receiver considered in Parts 2 and 3 is the British Dual-Standard Receiver which is capable, on operation of the "*Standard Selection*" control, of receiving programmes on either of these two considerably different systems.

Two decisions of particular importance had to be made in planning the Series. The first was to describe the working of the TV receiver almost wholly in terms of valves, even though in many of the latest single-standard and colour receivers the thermionic valve is being progressively replaced by semiconductor devices. This decision was made on two grounds. The first was that a large majority of the millions of receivers operational in Britain in the second half of 1971 are wholly or mainly valve-operated rather than transistorized and that, for technical and economic reasons which are more fully discussed in the final Section of Part 3 "TRENDS IN TV RECEIVER DESIGN", the valve will in all probability continue to play an important part in TV receivers, especially in those built on the Dual-Standard principle, for a significant number of years to come. The second reason was that, since the **COMMON-CORE** Series as it exists at present is planned on the basis of explaining the working of electronic devices in terms of current flow through a valve, it was desirable to keep this account of the basic principles on which television works compatible with the foundation **COMMON-CORE** volumes in their present form.

The other major decision in planning *BASIC TELEVISION* was to cover black-and-white ("monochrome") transmission and reception only, in the interest of keeping the descriptions of the various stages in the studio camera, the transmitter and the receiver relatively simple and relatively short. With the basic principles involved thus established (it is hoped) in the reader's mind, a further Series on *Basic Colour TV*, fully transistorized to reflect modern progress, is currently planned.

Most of the measurements given in the Series have been expressed (or in Part 1, which was first published in 1967, re-expressed) in SI Metric units. In particular, "Hertz" and "MHz" have been used in place of "cycles per second" and "Mc/s" throughout. But certain measurements either familiar to the viewer (*e.g.*, the sizes of picture tube) or else representative of orders of magnitude rather than of precise distances have been left in inches, miles, etc., as being more likely in that form to give the ordinary reader a clear picture of the point being made.

The Series has been written and illustrated to take its place in the growing **COMMON-CORE** Series of Illustrated Training Manuals on subjects connected with electricity and electronics. Originated in the United States by the distinguished New York firm of technical education consultants and graphiological engineers,

VAN VALKENBURGH, NOOGER & NEVILLE, INC.

the twenty-one Manuals of which the **COMMON-CORE** Series now consists have already sold over 1,500,000 copies in their British and Commonwealth editions. Six of the Manuals have been wholly conceived, written and illustrated in the United Kingdom; while all the remainder have been extensively rewritten to conform with British terminology and notation.

The *BASIC TELEVISION* Manuals presuppose in the reader a working knowledge of the contents of the foundation volumes of the **COMMON-CORE** Series, principally the five Parts of *BASIC ELECTRICITY* and the six Parts of *BASIC ELECTRONICS.* Prior acquaintance with the two-part series *BASIC ELECTRONIC CIRCUITS* will also prove useful when the operation of the TV receiver is studied in Parts 2 and 3.

The *BASIC TELEVISION* Series has been written, in conjunction with the editorial staff of the Publishers, by **Mr. H. A. Cole**, a Senior Scientific Officer in the Electronics and Applied Physics Division of the Atomic Energy Research Establishment at Harwell. Mr. Cole is a Chartered Engineer, and a Member of the Institution of Electronic and Radio Engineers. All illustrations of a technical nature have been drawn by Mr. Cole himself, with the Art Department of THE TECHNICAL PRESS responsible for their "decoration" and captioning.

TABLE OF CONTENTS

Section		Page
1	The Role of Television	1.1
2	The Basic Principles	1.5
3	Scanning	1.21
4	The Picture Signal	1.37
5	The Video Signal	1.68
6	The Television Studio	1.81
7	The Transmitter and Aerial	1.99
8	Signal Bandwidth	1.131

The COMMON CORE Series

of Basic Training Manuals
embraces so far the following titles:

BASIC ELECTRICITY

BASIC ELECTRONICS

BASIC SYNCHROS AND SERVOMECHANISMS

BASIC ELECTRONIC CIRCUITS

BASIC RADAR

BASIC INDUSTRIAL ELECTRICITY

BASIC TELEVISION

Foreword on International TV Systems

The television set round which this Series has been written is the so-called ***British Dual-Standard Set***, which is capable of receiving signals on two distinct line-systems—the 405-line and the British 625-line systems.

If you wonder at the emphasis placed on the word "British" in that phrase, "the *British* 625-line system", the reason for it is that it has regrettably not yet been possible to secure international agreement on all the technical details of any standard 625-line system.

For some time past, it has been the aim of the *C C I R* (*the Comité Consultatif International des Radio*, or *International Radio Consultative Committee*) to persuade all the countries of the world to adopt a common TV system, on the grounds that it would be of great benefit to everyone from the point of view of convenience, ease of programme exchange, and manufacturing economy. Although complete agreement is still a long way off, progress has certainly been made over the past few years.

There are at present seven major TV systems in the world: the American 525-line, the French 625-line, the French 819-line, the West European 625-line, the East European 625-line, the British 405-line, and the British 625-line systems. The British 405-line system is due to be gradually discontinued over the next few years and will eventually be replaced by a 625-line system.

Unfortunately, not all European countries—even the Western ones—agree on the technical details of a standard 625-line system. It is true that they agree on such important features as aspect ratio, scanning sequence, method of interlacing and a few others; but differences still exist over (for example) the choice of vision bandwidth, channel spacing, sound-to-vision carrier spacing, and the degree of modulation which shall correspond to black level. These differences, though not very great, can sometimes prevent satisfactory exchange of two 625-line programmes. For example, the 625-line system employed by Belgium and France uses amplitude modulation for the sound carrier, whereas all other European countries use frequency modulation. Similar differences exist elsewhere in Europe over the relative spacing of the sound and vision carriers.

The Western European and Eastern European systems differ mainly in the values chosen for channel width and vision bandwidth. The Western European system uses a 5 MHz vision bandwidth and 7 MHz channel spacing, whereas the Eastern European system uses a 6 MHz vision bandwidth and 8 MHz channel spacing.

The British 625-line system differs from both European systems in that it uses a 5·5 MHz vision bandwidth and 8 MHz channel spacing. Other differences concern the width of the vestigial sideband and the setting of the black level.

§ 1: THE ROLE OF TELEVISION

The world's first transmission of a regular televison programme was inaugurated by the British Broadcasting Corporation on the evening of November 2nd, 1936. On that opening night of the new service, the number of receivers in private hands which were capable of taking the programme radiated was very small. But the demand for sets soon started rising fast, and by the time the service had to be closed down in September 1939, Britain easily led the world with at least 20,000 sets in regular use.

Today, despite the seven-year interruption caused by the War, the number of sets in private households is some 12 million; and nearly 99% of the population could receive television transmissions in their own homes.

Elsewhere, the growth of TV has been comparable. In Europe, where the various national television services could not get under way again until well after the end of hostilities, the transmission of international programmes by *Eurovision* is now a regular event. In the United States (where a UNESCO report has estimated that there were no more than 5,000 receivers in use as recently as May 1941), Britain's figure of 12 million sets has long ago been left far behind. Other countries now transmitting television programmes designed, in varying degrees, for public information and entertainment include Australia, Russia, Japan, and many of the Republics of South America and of the more recently independent countries of Asia and Africa.

In Britain, since the transmission of television programmes was resumed by the BBC in 1946, the social impact has been enormous. Several independent companies relying for their revenue on televised advertisements began broadcasting their programmes from 1955 onwards; and a third national Television Channel (using, as you will see, somewhat different techniques) began to broadcast BBC 2 programmes in 1964.

Today, few British homes lack a television aerial sprouting from their roof-top; and "The Telly" has become a household word.

TV as Entertainment—and as a Cultural Force

The sheer entertainment value which this new electronic marvel can provide would have seemed, only a quarter of a century ago, almost fabulous. At the turn of a switch, artists and performers of every kind—men and women commanding the highest salaries in the world of entertainment—can be brought almost physically into the comfort of your own sitting-room, there to give what amounts to a private Command Performance in every home in the land!

Events taking place many hundreds of miles away can be similarly enjoyed, often at the very moment they are taking place—Lord's, Wembley, Wimbledon and St. Andrew's, Ascot, Aintree or Oulton Park, Trooping the Colour or the consecration of a new Cathedral. Add the vast range of music and drama presented, of spectacle and music-hall, of serious talks and not-so-serious quiz-games, of news broadcasts, symphony concerts and dancing competitions, of politicians, pop-singers, scientists, clergymen and visiting celebrities. . . . Not bad value there for a TV licence fee of a few pounds a year, if you care to think of things that way!

Together with the power to entertain, however, goes also the power to influence. It has been claimed that the result of a modern General Election can be swayed by the performance of a dozen politicians on TV; while no one who witnessed them on the television screen can ever forget the impact made by the living scenes of the Queen's Coronation in Westminster Abbey in 1953, or of the funeral of Sir Winston Churchill passing through the streets and up the River of London on that grey January morning in 1965.

The magic power of Television carries with it, therefore, a heavy responsibility. For even while it entertains, it cannot help but broaden the cultural interests of millions of its viewers. People who would never have considered paying to see a serious play, or listening to a Wagner opera, or visiting a Gallery to look at a masterpiece of modern art, have been enabled to discover in themselves interests which they never knew they possessed, and to derive from these interests a satisfaction of the mind quite different (in many cases) from anything they had ever experienced before.

It is estimated, by way of a single example, that more people watched the Laurence Olivier film *Richard III*, when it was televised recently in the United States, than had watched all the stage productions of all Shakespeare's plays put together, in all the 350-odd years since the plays were written. . . .

TV in Education, in Medicine and in Industry

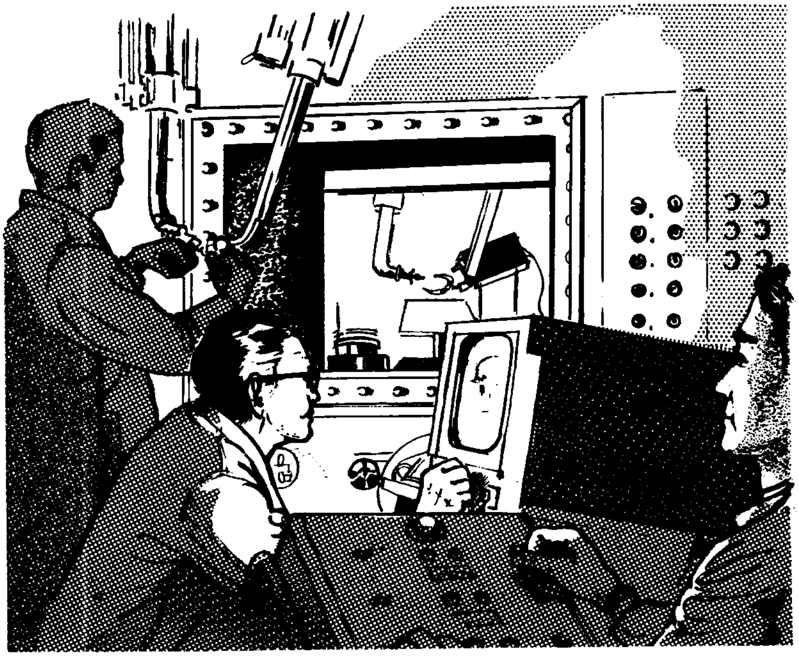
In Education, in Medicine and in Industry, television already has important applications; but far bigger possibilities lie ahead.

Lessons on specialist subjects are already, on a small scale, broadcast to schools. But Britain, it is said, faces a shortage of 70,000 teachers by the end of the 1960's. There could be an enormous saving of brain-power (and possibly an improvement in overall teaching performance as well) if whole courses could be taught to thousands of students by a single expert appearing at stated hours on TV.

In Medicine, many of our teaching hospitals today use TV cameras to take a continuous close-up picture of an experienced surgeon's hands at work on an operation. The picture is then relayed to a class of medical students in another room, where the twin problems of crowding and infection cannot arise.

In Industry, television is already much used, and will be more so. With its sound and picture impulses distributed in a "closed circuit" by land-line rather than through the air, widely separated executives in a large business can hold face-to-face conferences without loss of secrecy, or of time spent in travel.

Television can watch at close range things happening at critical points in an industrial process which are either inaccessible to a human being, or else too dangerous for him to approach (as when a TV set is used to monitor the remote handling of highly radioactive materials).



Other industrial uses of television, too numerous even to guess at today, undoubtedly lie ahead.

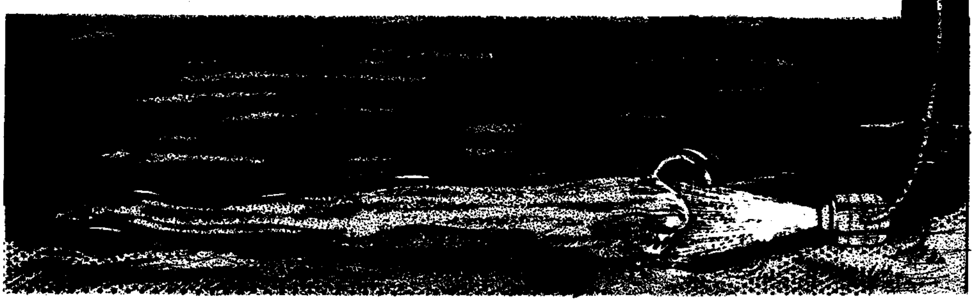
TV in Research into the Unknown

Most of the land surface of the Earth has now been fairly closely investigated; but exploration of the depths of the Ocean, or of the immensities of Space which surround our tiny planet, has scarcely begun. In both adventures, television will clearly play a major part.

The depth to which a human diver can descend is normally limited to a few hundred feet. Yet the greatest depths of the Ocean are much farther below sea-level than the summit of Mount Everest is above it! Suitably armoured, and equipped with proper lighting to pierce the utter blackness of the deep, TV cameras let down on cables from a ship can send back pictures of immense value—whether the quest be for a sunken ship or disabled submarine, or for a biological "snapshot" of one of the gruesome creatures that blindly hunt their sightless prey thousands of feet below the surface of the waves.

In Space, the Russians have already sent back televised pictures of photographs of the far side of the Moon, and the Americans (over a range of some 50 million miles) of the surface of the planet Mars. Circling the Earth as this is written are a number of American satellites whose function is to study the cloud formations that form and re-form over the Earth, and to send back pictures which may be of great value in the accurate forecasting of world-wide weather conditions.

EARLY BIRD, launched privately in the United States, is already transmitting TV pictures across the Atlantic; and planned for the near future are joint European-American launchings of satellites to be placed in orbit at intervals round the Earth. Their function is to receive, amplify and re-radiate radio-frequency waves modulated to carry TV pictures, and so to defeat the limitations on world-wide TV coverage imposed by the curvature of the Earth. Constantly recharged by thousands of solar cells set into the outer skin of their carriers, the batteries in these space-craft are planned to remain operational for years.



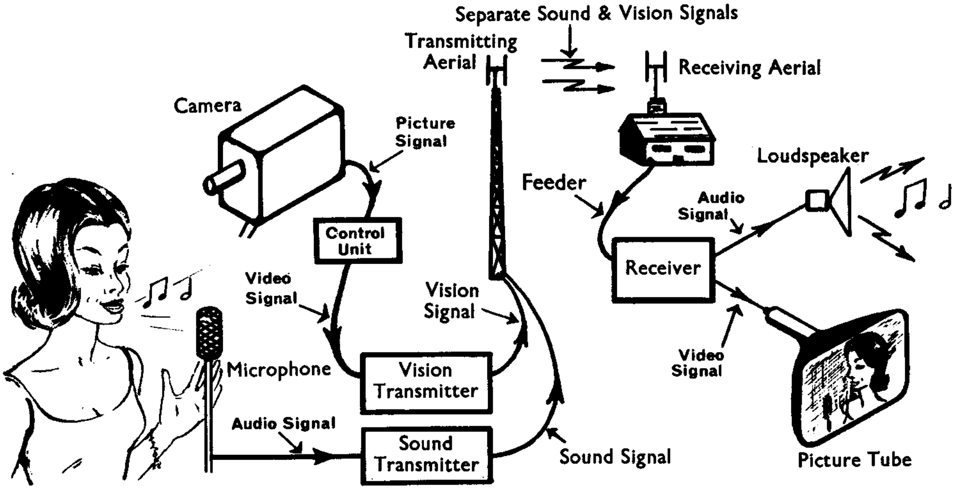
§ 2: THE BASIC PRINCIPLES

The major problems which a practical TV system has to solve can be stated as follows. A pretty girl is singing away in a television studio in London. How is it possible to transmit to a televison receiver some 50 miles away—

An instantaneous, moving picture of her appearance; and, simultaneously,

A faithful reproduction of the sounds she is making?

The block diagram below shows, in broadest outline, how it is done.



The sound waves actuated by the singer's voice are converted by a microphone into electrical impulses, which are amplified and conveyed (either by land-line or by SHF microwave link) to a radio-frequency transmitter, and then radiated from an aerial as in a normal radio broadcast. This is the **sound signal.**

Simultaneously, the girl's appearance is "scanned" by a television camera which is capable of detecting changes in the intensity of the light reflected from her person, and of converting these changes into electrical impulses. To these impulses (the **picture signal**) are added *synchronizing* and *blanking* pulses by a control unit in the studio, and the resulting **video signal** is fed to a separate transmitter, where it is imposed on another r.f. carrier wave. The resulting **vision signal** is taken to the same aerial as that used for the sound signal; and the two modulated carriers are radiated together.

In Part 2 of this Series you will see how the two separate and distinct signals are collected by the receiving aerial and passed to the TV receiver. This remarkable "Magic Box" converts the two signals back into sound emitted from a loudspeaker and into a picture displayed on a special screen.

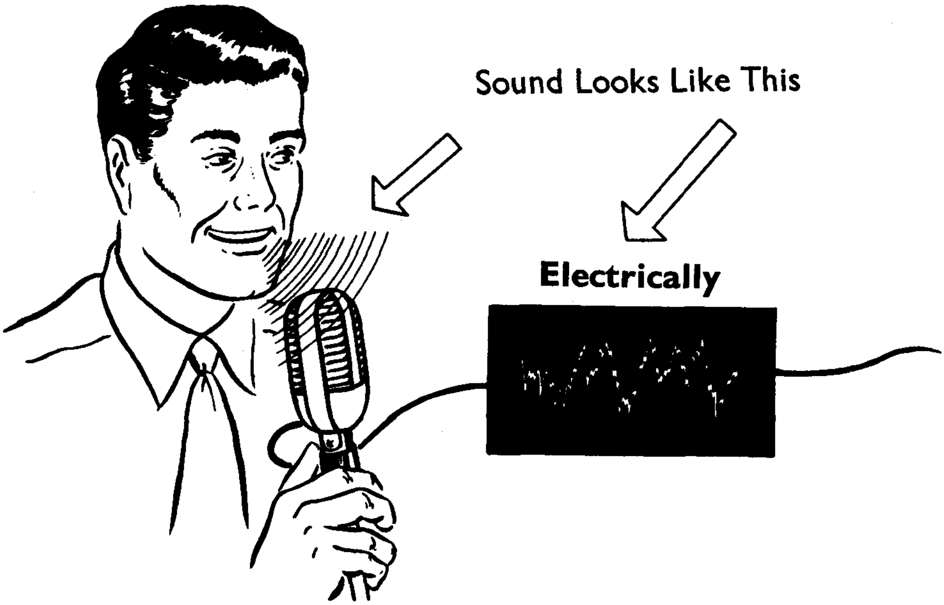
A TV system can therefore be broken down into six main tasks:

1. **The Conversion of Sound and Light into electrical impulses;**
2. **The Combination of these signals with separate high-frequency carrier waves at a Transmitting Station;**
3. **The Radiation of the now-modulated carriers by the Aerial System;**
4. **The Reception of the sound and vision signals by the Receiving Aerial;**
5. **The Separation of the two signals in the Receiver; and**
6. **The Presentation of the picture signal on the Picture Screen, and the Emission of the original audio signal from the Loudspeaker.**

The Sound Signal

The conversion of sound waves into a series of electrical impulses is a process already familiar to you from your reading of *Basic Electricity* and *Basic Electronics.* You learnt, for instance, in the very first Part of *Basic Electricity* that one of the six basic methods of producing electricity was **pressure**; and in the second Part of *Basic Electronics* that sound was no more than the movement of pressure waves through the air.

When these sound waves reach a microphone, the variations in air pressure they produce actuate a diaphragm in the microphone, and cause it to produce an a.c. voltage. The frequency of this voltage is identical to the frequency of the sound wave which produced it, and its amplitude is proportional to the loudness of the sound itself.



The sound signal thus produced is amplified, and passed to the modulator stage of the sound transmitter. Here it is used to modulate the amplitude (or, in the case of an FM system, the frequency) of an r.f. carrier wave. After modulation, this carrier is further amplified, and is then taken through special feeder lines to a transmitting aerial—all just as you learnt in *Basic Electronics.*

At the receiving end of the link, a single aerial (usually mounted on a chimney) detects the r.f. carriers with their audio and video modulations, and feeds them to the receiver. The signals are amplified, and then converted into i.f. signals by normal superheterodyne action. The sound i.f. signal is separated from the vision i.f. signal by means of special filter circuits, and passed to the sound detector. Here the modulation is removed from the carrier, amplified once more, and applied to the loudspeaker.

In this way, the actual sounds detected by the microphone in the studio are reproduced in your own home.

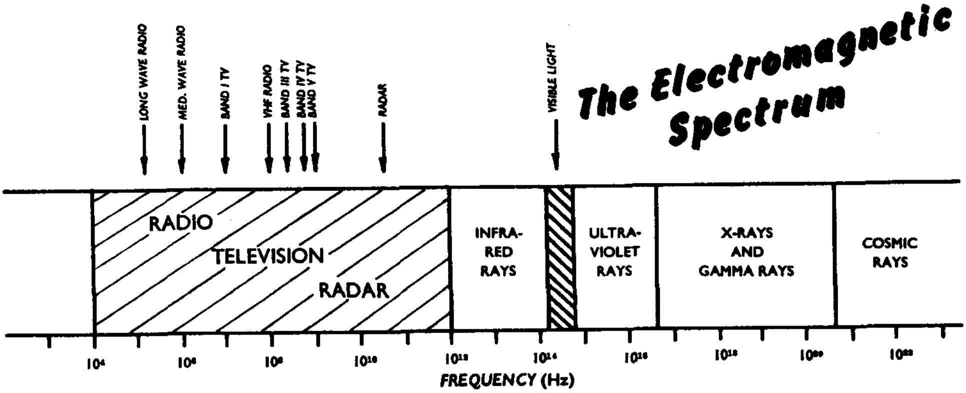
The Vision Signal—What is Light?

Your next job is to find out how the same thing is done for Light as you already know how to do for Sound. Here you will find yourself on ground that is wholly new to you; so you must begin by learning something of what Light itself is.

In your study of *Basic Electronics*, you investigated certain properties of radio waves. You know, for example, that a normal medium-wave sound broadcast makes use of radio waves having frequencies lying between 300 kHz and 3 MHz per second. As frequencies get higher, you pass through the short-wave sound broadcast band, then through the frequencies used in television, until you reach the frequencies at which radio waves can be used in radar. If you have read Part 1 of the companion Series to this book called *Basic Radar*, you will know that bands used in modern radar range from about 225 MHz to something of the order of 300,000 MHz.

What happens when frequencies get higher still? Well, a good many things happen; but one in particular is that as the frequency of the radiation approaches the very high figure of 400 mega-mega Hertz (4×10^{14} Hz), it begins to take a form which the human eye is able to pick up as **Light.**

Light reaches your eye, as you will see on the next page, in a number of different forms. But the point to grasp now is that your eye can detect light waves only over a comparatively narrow, strongly-defined band of frequencies—from about 4×10^{14} to about $7{\cdot}5 \times 10^{14}$ Hertz. This range is known as **the waveband of visible light.** You can see the position occupied by this narrow waveband in the full **Electromagnetic Spectrum** (as it is called) illustrated in the chart below.



You will see from the above that the electromagnetic radiations which your eye picks up, and which your brain recognizes as *Light*, are essentially the same phenomenon as radio waves, but on a different scale. It is not surprising, therefore, that they obey the same physical laws in their behaviour.

You would not, in fact, be very far wrong if you looked on the human eye as a specialized kind of radio receiver—one which is capable of receiving radiations of a certain (ultra-short) wavelength and of converting them into signals which it passes on to the brain.

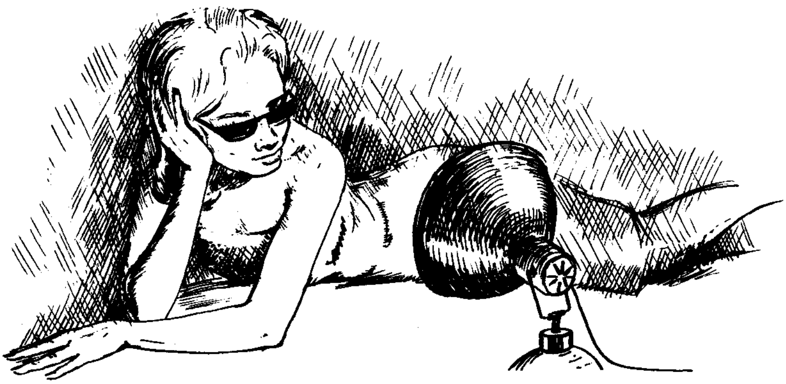
What is Colour?

You have just seen that the waveband of visible light extends over a narrow range of frequencies. Within this waveband, different sub-ranges of frequencies convey to your eye differing sensations—and these differing sensations we know as **Colour.**

Light of the lowest frequency visible to the human eye appears to us as **red.** (Radiations having frequencies just below that of "red light" transmit to us the sensation we call **heat.** You have heard of the "infra-red cooker". *Infra* is Latin for *below*; so if you have equipped your wife with a cooker of this kind, you may be interested to know that your mid-day meal next Sunday will have been cooked by radiations having a wavelength just below those which enable your eye to detect an ordinary G.P.O. letter-box outside the window!)

In order of increasing frequencies above Red, Light presents itself to the eye in a number of gradually differing hues. Some people can detect as many as a hundred of them; but the seven principal ones, called the **spectral colours,** are (still in ascending order of frequencies): **Red, Orange, Yellow, Green, Blue, Indigo** and **Violet.** These seven are the main constituents of what is called the **spectrum of visible light.** You can inspect this spectrum if you shine a strong white light through a triangular glass prism on to a piece of white paper. Or you can look carefully the next time you see a rainbow. . . .

Beyond violet, radiations of still higher frequencies, though you cannot see them, can nevertheless damage your eyes. That is why people receiving therapy (or merely "cooking" their skins to a becoming shade of brown!) by means of "ultra-violet ray" lamps need to wear special spectacles to exclude the damaging radiations with their "beyond-violet" frequencies.



So would anybody who risked exposing their eyes to the so-called "X-rays", which are merely radiations having higher frequencies still.

To sum up briefly, then, so far. Radio and radar waves, heat, light in its various colours, and X-rays—all these are alike in that they consist of electromagnetic radiations of different wavelengths, but otherwise of the same basic type. Once you have grasped this cardinal fact, the problem of converting light into an electrical impulse begins to look a good deal less formidable that it once did.

How Light is Produced

You will remember that the atoms of every element consist of a nucleus, and of a number of electrons circling in orbit round it—the number of electrons (and therefore the balancing positive charge on the nucleus) being different with every one of the 92 natural elements, and with all the eleven synthetic elements which Man has since added to that number.

These electrons circle the nucleus of their atom in fixed orbit paths, or "shells", each at a varying distance from the nucleus and each containing (in conditions of stability) a fixed number of electrons. Two electrons complete the innermost shell of all atoms, for instance, and eight (in atoms which have 10 or more electrons) complete the next one out.

All atoms fill their innermost orbits first, and hate leaving these inner orbits incomplete. They therefore betray a strong desire to "pull in" outer electrons to fill the place of any they may lose from an inner orbit.

You learnt in Part 2 of *Basic Electricity* that the outermost electrons of some atoms are fairly easily stripped away from their atom altogether, and become free. (This is particularly liable to happen if they are travelling in an orbit which is incomplete.) But a very much greater "kick" of energy is needed to knock away from an atom one of its *inner* electrons—either into an orbit more remote from the nucleus, or even away from the atom altogether.

When such a kick arrives, an outer electron instantly drops into the place left empty in the inner shell. As it does so, it has to adjust itself quickly to the conditions ruling in its new orbit. In particular, being now in a narrower orbital path round the nucleus, it has to slow down. One of the ways in which a moving body can slow down is to give up energy. Your car slows down by giving up energy to its brakes in the form of heat;

Electrons slipping into an Inner Orbit give up Energy in the form of High-Frequency Radiation.

The great German physicist, Max Planck, showed in the early years of this century that the greater the amount of energy surrendered by an electron slowing down, the higher the frequency of the resulting radiation would be.

Now different atoms, as you know, have different numbers of electrons circling in orbit round their nucleus. When one of these electrons moves into an inner orbit, it surrenders a quantity of energy which varies with the proximity to the nucleus of the orbit into which it moves. Generally speaking, the closer in to the nucleus the movement takes place, the greater the quantity of energy surrendered—and therefore the higher the frequency of the radiation given off.

You know that heat, light in its different colours, and X-rays are all radiations of different frequencies. All are produced by the movement of electrons into vacancies caused in the inner orbits of different atoms by a kick of energy coming from outside.

How Light is Produced (*continued*)

Take as an example of the process described on the last page radiations on two frequencies within the waveband of visible light. It has been found that agitation of the electrons circling the nucleus of the element sodium will produce a wave of light having a frequency in the range of yellow/orange; while mercury produces light of a steely blue colour. You can see the difference if you look at sodium-filled street lamps, and compare their light with that given off by mercury-filled ones.

But whatever the colour of the light to which agitation of the atoms of any material gives rise, the strong "kick" of energy needed to dislodge electrons from the inner orbits of these atoms has got to come from somewhere.

By far the most important source of this extraneous energy available on Earth is the Sun. Electromagnetic waves generated in the Sun by its own tremendous internal heat travel the 93-odd million miles to Earth, and still have enough energy left to agitate the atoms of elements on which they fall, and to make them give out radiations of their own on their own particular wavelengths. This is what you really mean when you say that you perceive objects "by daylight". You see them because your eye detects radiations knocked out of their surface atoms by the sharp kicks of energy they receive from the light of the Sun.

Where does Pure White Light Come From?

When you were reading, a page or two back, the list of the spectral colours which make up the spectrum of visible light, you may have thought it odd that white did not figure on it. White is not in fact a spectral colour at all. Oddly enough, it is a combination of a great many other colours; and *true white light is produced only by a combination of every single frequency within the entire waveband of visible light.*

The principal source of pure white light known to us is the Sun, and (if you ignore minor imperfections in the purity of its light caused by its own atmosphere) you can say that

The Pure White Light of the Sun

Contains the Frequencies of

Every Colour in the Visible Spectrum

How Light is Produced (*continued*)

You saw on the last page that the light-waves from the Sun are capable of agitating all the atoms whose resulting radiations produce in your eye the sensation of seeing "every colour in the rainbow". But what happens when the Sun is not there? On a pitch-dark night, for instance, there is no radiation from any source capable of agitating the surface atoms of any object around you—and you will see nothing at all.

For thousands of years past, Man has unconsciously solved the problem of supplying the initial kick of energy needed to produce light by the same basic means as is used in the Sun—namely, by the application of heat. At first, probably, by using a blazing torch; later by setting fire to some sort of wick set in some sort of oil or grease; more recently still, by passing an electric current through a piece of conductor wire and so heating it.

But although Man has got fairly close to rivalling the perfect whiteness of the Sun's light with some of his recent inventions, he has not done so yet; and no artificial light yet produced will enable your eye to see all the colours of the visible spectrum in their exactly correct proportions.

Look, for instance, at a red pillar-box by the light of a mercury-filled street-lamp. It will hardly look red at all. For a pillar-box appears to us as "red" only when the light shining on it contains the frequencies which are capable of agitating the atoms of those elements on its surface which in turn are capable of giving off red light. The pillar-box, in other words, "reflects" only the "red frequencies", and "absorbs"—i.e. fails to reflect—all the rest. If the light striking the pillar-box contained no red at all (and if the spectrum of visible light were more sharply defined than in fact it is), you would barely be able to post your letters until the pillar-box was painted some other colour; for you would have great difficulty in finding it.

That is why things appear to change in colour when the character of the light falling on them changes. You know (or, if you don't, your wife will) how different the colours in a frock or a piece of material can look under different conditions of light —and how important it is to inspect them, before buying, in those conditions of light in which they will most often be seen.

What the woman in the picture is actually doing (though she probably doesn't realize it) is trying to get the light-waves falling on the bit of stuff she is holding to include all those of the correct frequency!

How Light Becomes a Signal

You have seen how one form of energy—Heat—is used to create another form of energy—Light. You must now see how the energy of light is converted into a third form of energy—Electricity. For you know that the Vision Signal you are interested in is itself an electrical impulse.

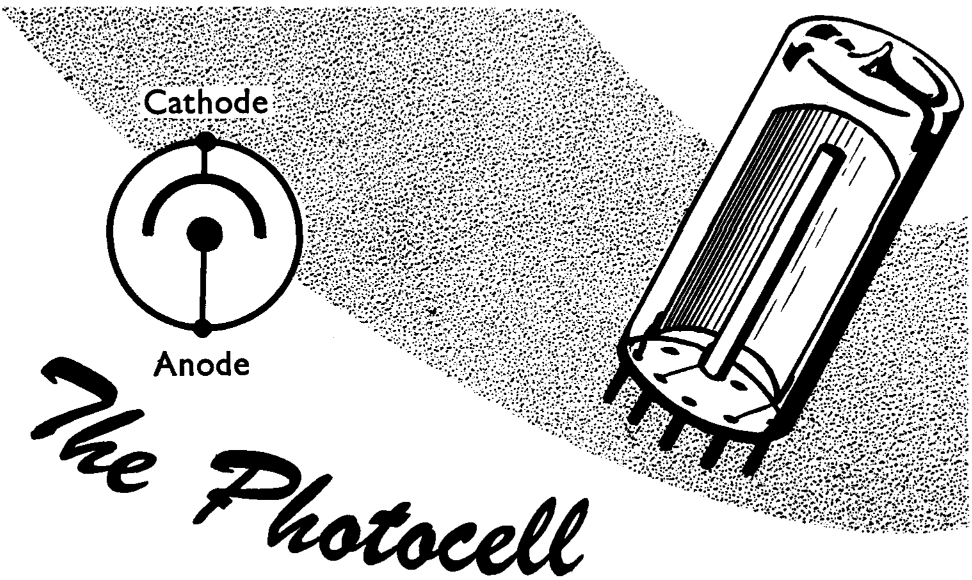
There exist in Nature certain elements which behave in rather an odd way when rays of light fall on them. They are, in other words, sensitive to light—or *photo-sensitive*, as the effect is called.

The two kinds of photo-sensitivity with which you will be concerned in this Series are **photo-electricity** and **photo-conductivity**, for both phenomena are used in modern TV camera tubes. (The third main kind of photo-sensitivity, by the way—it is called the *photo-voltaic effect*—is put to use in the solar cells which continuously recharge the batteries of many of the satellites which are now orbiting the Earth.)

Photo-electricity

When rays of light fall on a surface coated with certain elements, the energy of the rays knock electrons right out of the coating material, and sets them free. Examples of such *photo-electric* (or *photo-emissive*) elements are zinc, potassium, sodium and—especially—caesium. One of the most sensitive photo-electric materials yet developed is a strip of metal coated with silver oxide, on top of which a thin film of caesium has been deposited.

An important application to which a strip of metal treated in this way has been put is in the *photo-electric cell* (or **photocell,** as it is generally abbreviated), about which you must now learn. The illustration on the right below shows what an operational photocell looks like. On the left appears the symbol by which a photo-cell is conventionally represented in electrical diagrams. As you will see on the next page, it is essentially a representation of what the photocell looks like when it is viewed from on top.



The Photocell

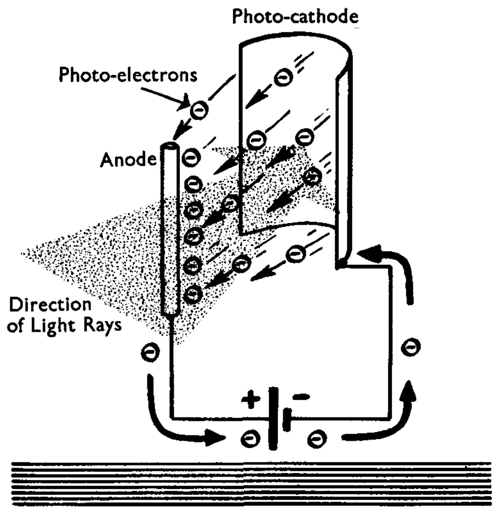
You will remember that in the ordinary thermionic radio valve the cathode, when heated, emits electrons which are attracted to and collected by the relatively positive anode, and that an electric current results.

In the photocell, a strip of metal coated on its inside surface with a film of photo-electric material is made into the shape of a semi-cylindrical plate. It is then placed close to a rod-type anode; and the whole assembly is enclosed in a glass envelope from which two leads are taken to the outside.

The anode is, as before, given positive polarity; while the semi-cylindrical plate (which is called in this application the **photo-cathode**) is energized by the focusing on to its interior surface of rays of light. When this happens, electrons are emitted. They are collected by the anode, and an anode current flows.

Within certain limits, the value of this current is linearly related to the degree of illumination falling on the photo-cathode—the brighter the light, the greater the current. Operating currents in a photocell are, however, extremely small, being typically of the order of 1.5 to 10 micro-amperes.

If a load be connected in series with the anode of the photocell, a voltage will be developed across this load whenever the photo-cathode is illuminated. The greater the degree of illumination, the more current will flow, and the greater will be the voltage developed across the load.



You will see at once that you have here a device capable of converting light-energy into electrical signals; and the photo-emissive principle is in fact used in most (but not all) modern TV cameras.

Other uses for the photocell include a special type of burglar alarm. When the thief moves across a beam of light, *which need not necessarily be within the visible spectrum*, he momentarily shields the photo-cathode, cuts off the current and with it the voltage across the anode load, and so actuates the alarm mechanism.

Another use is in a set of garage doors which open themselves when a car's head-lights are shone on to a conveniently situated photocell. The voltage developed across the anode load of the photocell operates a relay switch, which in turn starts up an electric motor opening the garage doors.

Photo-conductivity

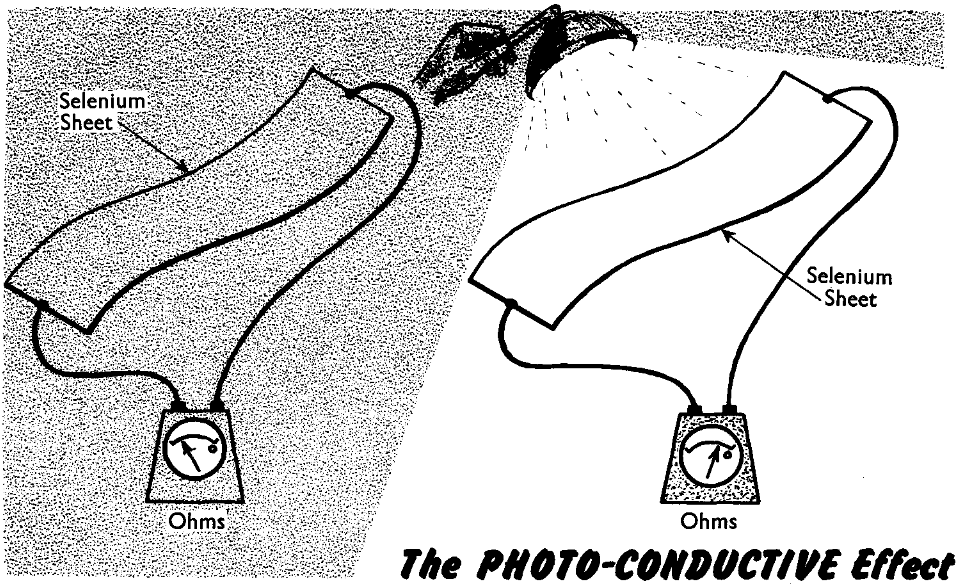
The other main type of photo-sensitivity of interest to you in the conversion of light into an electrical impulse is **photo-conductivity.**

When certain materials—of which selenium is a leading example—are exposed to light, their resistance to the passage of electrical current is diminished. In other words, their conductivity improves.

You will recall that, in the photo-electric effect, the rays of light striking the photo-sensitive material caused electrons to be given off *from the surface of the material.* In the photo-conductive effect, on the other hand, the rays cause electrons to be liberated *within the material itself.* More free electrons within a piece of material, as you know, increase its conductivity.

The resistance of a piece of clean selenium is considerably changed when it is exposed to light. The amount of the change even varies with the colour of the light itself—a fact which should not surprise you after what you have learnt of the different frequencies which give rise to different colours being observed by your eye.

Once darkness is restored, the electrical resistance of selenium reverts to normal.



The PHOTO-CONDUCTIVE Effect

For TV purposes, however, there is one important disadvantage in the response of selenium (and of a good many other materials having similar properties) to the application and removal of light.

This disadvantage is that conductivity does not change to its new value at once. In other words, there is a *time-lag.* When light is applied to it, the conductivity of selenium rises only gradually to its new value. When the light is removed, it reverts only gradually to its darkness level—dropping rapidly at first, then increasingly more slowly.

The full time-lag between removal of the light and restoration of the old level of conductivity was at one time as long as a whole second. It has been greatly reduced by modern manufacturing techniques; but cameras using the photo-conductive effect are still inferior to those using the photo-emissive effect when scenes of fast movement are being televised.

How a Camera "Sees" a Scene

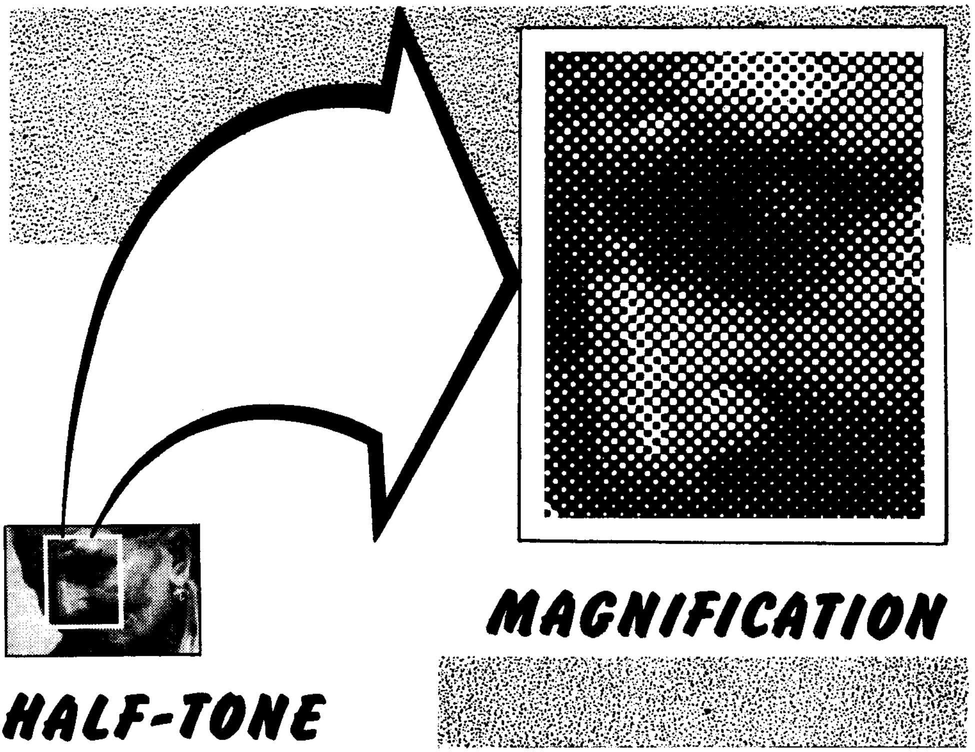
You have just seen that a photocell can convert light into electrical signals, and—more important still—that *it can vary the strength of these signals according to the intensity of the light it receives.* It performs this "conversion act", and the variations upon it, very quickly indeed—so quickly as to make it almost instantaneous.

Fine, you may say—but how do "variations in the intensity of light received by a photocell" help to televise the finish of The Derby . . . ?

Consider closely what an ordinary black-and-white "still" picture printed in a newspaper really consists of. Say it is a photograph of an old woman's face.

If you look at it through a magnifying glass, you will see that the picture is really made up of thousands and thousands of tiny individual areas of black and white. The white dots present always the colour of the paper itself; the black ones are all of exactly the same degree of blackness. *What varies is their relative density of packing.*

In the process used, which is known as *half-tone photo-engraving*, the black dots are packed so tightly together on those areas of the printed image which represent the darker areas of the old woman's face that they seem to coalesce. In other words, the black dots appear to vary in size according to the *tonal content* of the different areas of the picture.



How a Camera "Sees" a Scene (*continued*)

Every individual black dot in the process described on the last page is known as a **picture element.** It represents the smallest detail of the picture which is capable of being reproduced. In the magnification illustrated, it is the *smallest* black dot you can see in the *lightest* area of the picture.

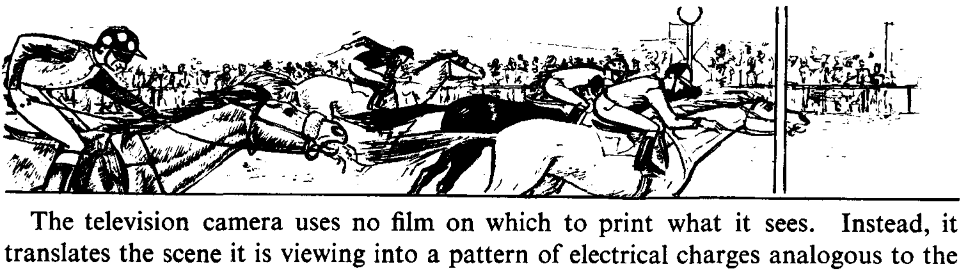
Most newspaper photographs are made up of comparatively large picture elements, generally big enough to be visible to the naked eye. Greater clarity of detail would be possible if all the black dots were kept much smaller, and if their density was increased wherever darker areas had to be represented. But paper of better quality than ordinary newsprint would be necessary for this method to be successful. (Compare, for example, the quality of the photographs reproduced in *The Times* with those in a mass-circulation journal using less good paper.)

Whatever the details of the method, the essential point of the half-tone process is that all the intermediate tones between black and white—that is to say, all the various shades of grey—can be effectively presented by a suitable arrangement of the picture elements, which are all pure black, on a white background of paper.

Now go back to your Derby finish. Assume that you are *photographing* it in black and white only. The photographic print method which your camera will be using differs considerably from the half-tone process you have just been examining; but the principle on which it works is identical. Intermediate tones are represented by varying concentrations of minute areas of black and silver, which here does the job of white.

The next step is to take a *series of such photographs* in very rapid succession. Each of them will differ slightly from its predecessor as the horses and their jockeys move on. Present this succession of slightly different photographs one after the other to the human eye—and you will have been to the cinema sufficiently often to know that if you do it fast enough, the illusion of smooth and continuous movement will be created.

But this extra refinement in no way alters the fact that what you are looking at is essentially no more than a constantly varying arrangement of black and white dots.



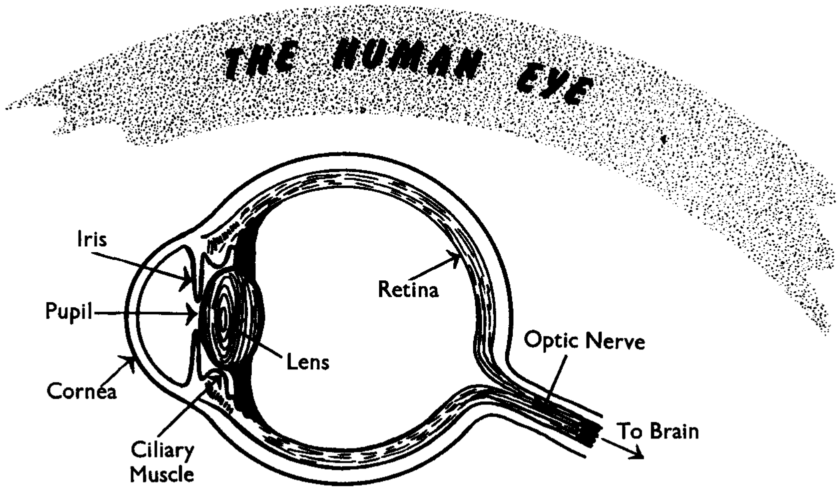
The television camera uses no film on which to print what it sees. Instead, it translates the scene it is viewing into a pattern of electrical charges analogous to the black dots used in the half-tone process. The smallest of these charges represents a picture element, or *elemental area* of the scene. The job of the TV camera is to convert these elemental areas into electrical signals whose amplitudes vary with the amount of charge on the element.

The ability of a photographic image-reproducing process to present the finer detail of a scene is known as its *resolving power*, and the picture is said to be "of good (or poor) *resolution*". In TV language, however, the word **definition** is always preferred.

How your Eye Sees a Scene

Compared with any mechanical/electronic "seeing system" yet invented, the human eye is a marvellously efficient optical instrument; and you should have some idea of how it works.

Reduced to its basic essentials, your eye is a crystalline lens system which collects light *of all frequencies in the visible spectrum,* and focuses it on to a light-sensitive screen (called the **retina**) situated in a concave arc round the back of the eye.



The retina itself is made up of millions of nerve fibres, each sensitive to light of a different frequency, which are connected in groups to the **optic nerve.** This nerve, in turn, is connected to the brain. When an image is focused on the retina, signals from those particular groups of nerve-fibres which are sensitive to the frequencies involved are instantaneously transmitted *via* the optic nerve to the brain; and the sensation called **sight** is created.

The focusing of the image on to the retina is done by the **lens system** of the eye. The ciliary muscle controls the degree of curvature of the crystalline lens, and therefore its focal length.

Since the nerve fibres in the retina are very delicate and could be damaged by sudden large changes in the quantity of light falling on them, there is situated between the lens itself and the outer **cornea** (whose job it is actually to collect the light) an adjustable curtain called the **iris.** This curtain varies in colour from person to person. When you say that a girl has blue, or brown, or green eyes, it is her iris that you are really talking about!

In the centre of the iris is a circular aperture called the **pupil** of the eye. The muscle which controls the iris relaxes and fully opens the pupil when the eye is observing a dark scene; but when strong light is present, the muscle reduces the pupil to little more than the size of a large pin-head. In this way the light collected by the cornea is controlled in amount before it reaches the lens and is focused by it on to the sensitive retina.

Persistence of Vision

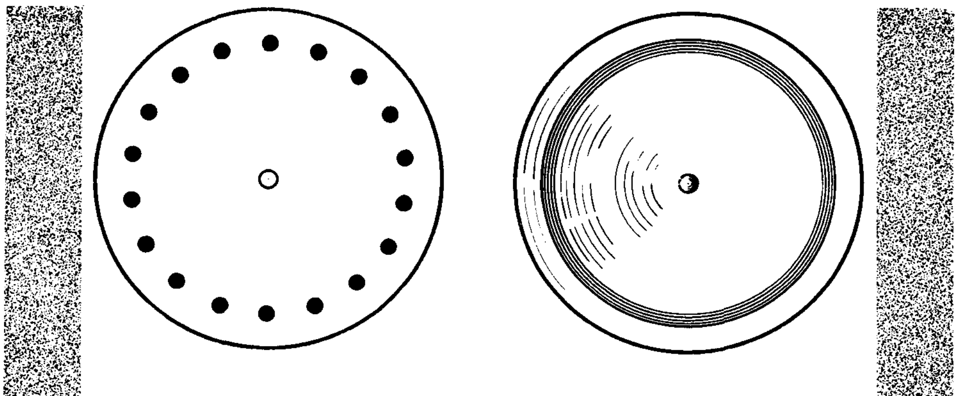
By means of the optical mechanism outlined on the last page, the eye is able to present to the brain, directly and instantaneously, a complete picture of the object viewed —its three dimensions of height and width and depth, its tonal content, and every shade (wavelength) of colour within the visible spectrum which the surface of the object has the power to reflect.

But the eye has also another attribute of the highest importance. It is called **persistence of vision,** and it can be defined as follows:

The Human Eye possesses the ability to Retain an Impression of the Shape, the Colour and the Brightness of an Image for a Fraction of a Second after Light from the Image has Ceased to be Received.

This property of the eye plays an essential role in the reception of both cinematic and television images; for it means that the illusion of a continuous picture can be obtained from a series of individual images, each differing slightly from its predecessor, presented to the eye in very rapid succession.

You can easily demonstrate to yourself the principle of persistence of vision by marking out near the rim of a stiff paper disk, some four or five inches in diameter, a series of heavy black dots, and then rotating the disk rapidly about its centre. As good a way as any of doing this is to "play" the disk on the turn-table of a record-player. You will see that, above a certain speed of revolution, the individual dots lose their separate identities, and appear to merge into a continuous grey circle.



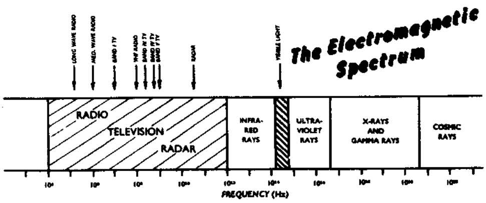
DISK AT REST **DISK IN ROTATION**

REVIEW of the Basic Principles of TV

Visible Light is an electromagnetic radiation of the same general nature as a radio wave, and obeys the same physical laws. It is, however, of much higher frequency.

The electromagnetic radiation which gives rise to Visible Light is occasioned when a "kick" of energy (generally heat) from an outside source displaces an electron from an inner shell of an atom. An electron from an outer shell promptly drops into the vacant space, and in doing so surrenders energy in the form of a radiation having a wavelength lying within the Waveband of Visible Light.

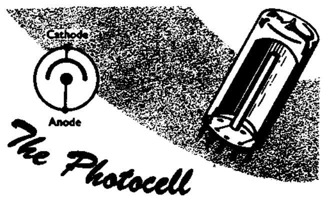
The Waveband of Visible Light is a narrow band of frequencies higher than those which give rise to the phenomenon of heat, but lower than the frequencies of the ultra-violet and X-rays. It lies between about 4×10^{14} and $7{\cdot}5 \times 10^{14}$ Hertz.



The Spectral Colours within the Waveband of Visible Light are (in order of increasing frequency) *Red, Orange, Yellow, Green, Blue, Indigo* and *Violet.* Pure white light is a combination of every frequency in the visible spectrum.

Objects appear to the human eye to be of a certain colour only when the light falling on them contains the frequencies which give rise to that colour.

The Photo-electric Effect occurs when rays of light strike a surface coated with certain elements—notably caesium—and the energy of the rays knocks electrons right out of the coating material and sets them free.

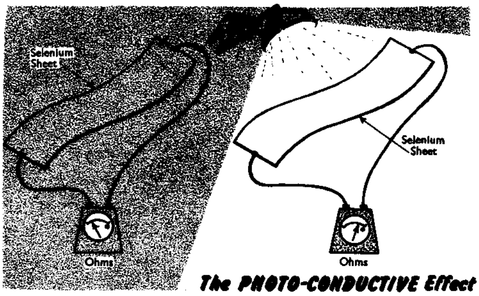


The Photocell is a device for turning Light into electrical signals by making use of the Photo-electric Effect. A rod-type anode is enclosed in a glass envelope with a semi-circular cylindrical plate (called the *photo-cathode*), which is coated on its inside surface with a film of photo-electric material and is placed close to the anode. This anode is connected to a battery so as to be made positive with respect to the cathode. When light is focused on to the interior surface of the photo-cathode, electrons are set free and are attracted to the positive anode. An anode current then flows.

The magnitude of this current depends on the intensity of the light striking the coated surface of the photo-cathode, and varies almost instantaneously with it.

REVIEW of the Basic Principles of TV (*continued*)

The Photo-Conductive Effect. When certain materials, notably selenium, are exposed to light, their resistance to the passage of electrical current is diminished and their conductivity improves. When the light is removed, the conductivity of the material returns to its former level. The effect thereby provides another means of converting light of varying intensity into an electrical signal of varying amplitude.



The PHOTO-CONDUCTIVE Effect

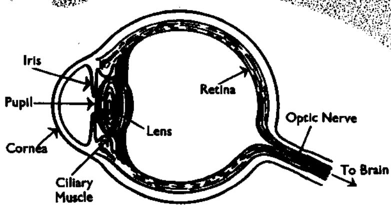
The changes in conductivity of the photo-conductive materials do not, however, take place instantaneously; and the resulting time-lag is a disadvantage in TV cameras using this effect when they are used to record fast-moving scenes.

The Picture Element is the smallest area in any picture which it is possible to present in any process of image reproduction. In the familiar photographic print, the picture elements are minute grains of light-blackened silver, clustered either thickly or less thickly on the darker and lighter areas of the picture respectively. In the newspaper-type half-tone, they are black dots. In the TV camera, they are minute electrical charges.

In all systems, it is the size of the picture elements which determines the amount of detail in the scene which the system is capable of resolving. The smaller the picture elements, the greater the definition of the system.

Definition. The ability of any photographic image-reproducing process to present the finer details of a scene is known as its *resolving power* or *definition.*

THE HUMAN EYE



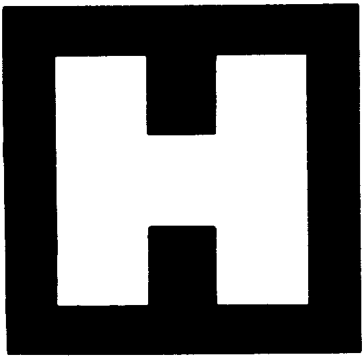
Persistence of Vision. The human eye possesses the ability to retain an impression of the shape, the colour and the brightness of an image for a fraction of a second after light from the image has ceased to be received.

§ 3: SCANNING

If a television system is to operate effectively, it must be able to produce at some distant point an apparently instantaneous and continuous record of all the essential details comprising the scene being televised. Ideally it should reproduce an image identical in every respect to that observed by the eye.

But you have just seen that the human eye is capable of examining *simultaneously* all the structural content of the image focused on the retina, and of conveying this information without delay to the brain. If a television system is to be able to emulate the eye, it too must perform a *simultaneous* and *complete* examination of the entire scene, and reproduce it at the receiving end of the link.

Although such a feat is theoretically possible, it is worth spending a moment or two looking at the type of equipment that would be necessary to perform it, to see why something more practical has to be devised.



Take an exceedingly simple scene—merely a letter **H** painted in shiny white paint on a black background. It is indicated by the figure ❶ in the illustration across pages 1.22 and 1.23, and is strongly illuminated by direct light from the lamp ❷. This light is reflected ❸ from the scene, much more strongly from the bright, smooth surface of the **H** than from the black, matt surface of its background.

Directly facing the scene is a panel ❹ holding enough photocells (only 25 are actually shown) to be able to cover every square inch of the scene. Each photocell is so recessed in an open-ended tube that it is shielded from all light other than that reaching it from the area of the scene it is "watching".

The light accepted by each photocell is converted by it into a separate electrical signal—the more intense the light, the larger the amplitude of the signal; and these signals are conveyed, each by a separate wire ❺, to a bank of 25 amplifiers ❻. These amplifiers are needed to "step up" the signals to a strength adequate for feeding into an array of 25 more wires ❼—and very long ones this time—connected to the distant receiver.

Note that it is at the point where the 25 separate signals call for 25 separate amplifiers that the bulk and cost of this theoretical arrangement begins to become heavy.

Note also that the 25 long wires could in theory be replaced by 25 separate transmitters which would radiate the signals as radio-frequency waves. This would supply the signal to many receivers simultaneously; but it would call for an enormous frequency bandwidth for the 25 simultaneous transmissions to be possible without serious mutual interference.

Why "Simultaneous TV" is Impracticable

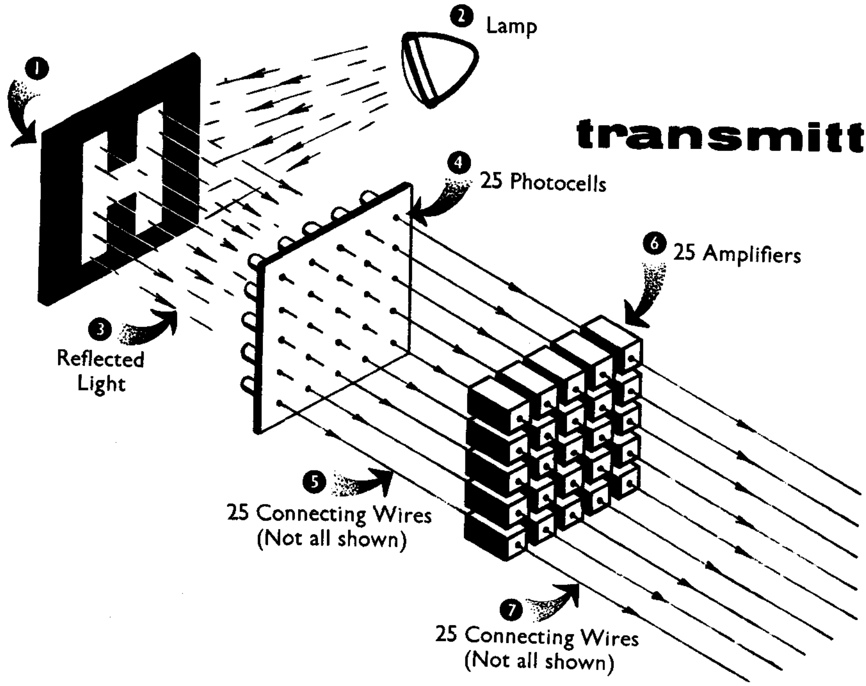
When the signals of this theoretical TV system reach the receiver, they will again need amplification. You have, therefore, a second bank of 25 amplifiers ❽, connected to a panel ❾ on which are mounted 25 lamps, each focused on to a small area of the viewing screen ❿. The larger the amplitude of the signal leaving each amplifier, the brighter will shine the lamp it controls, and the stronger will be the beam which that lamp throws on to the viewing screen.

Every lamp at the receiver is carefully connected to that photocell in the transmitter which occupies the same position on its panel as the lamp in the receiver does on *its* panel; so that the more strongly a photocell sends a signal on its way, the brighter will glow the corresponding lamp on the panel in the receiver.

In this way, a letter **H**—of a sort—will be thrown on to the viewing screen; and the system as a whole can be said to work.

But you will note that the **H** at the viewing end is formed of eleven rather ill-defined "areas of illumination" only, and is consequently very inferior in definition to the original **H** in the scene. This inferiority would have been even more marked if the scene had been more complex. It would, for instance, have been difficult to reproduce a convincing letter **C** by this process—while as for the finish of the Derby . . .!

THEORETICAL SIMULTANEOUS



Why "Simultaneous TV" is Impracticable (*continued*)

This inability to resolve fine detail is, of course, principally due to the comparatively small numbers of lamps and photocells used in the "system" illustrated. If the number of both were substantially increased, the resolution of the system would be somewhat improved.

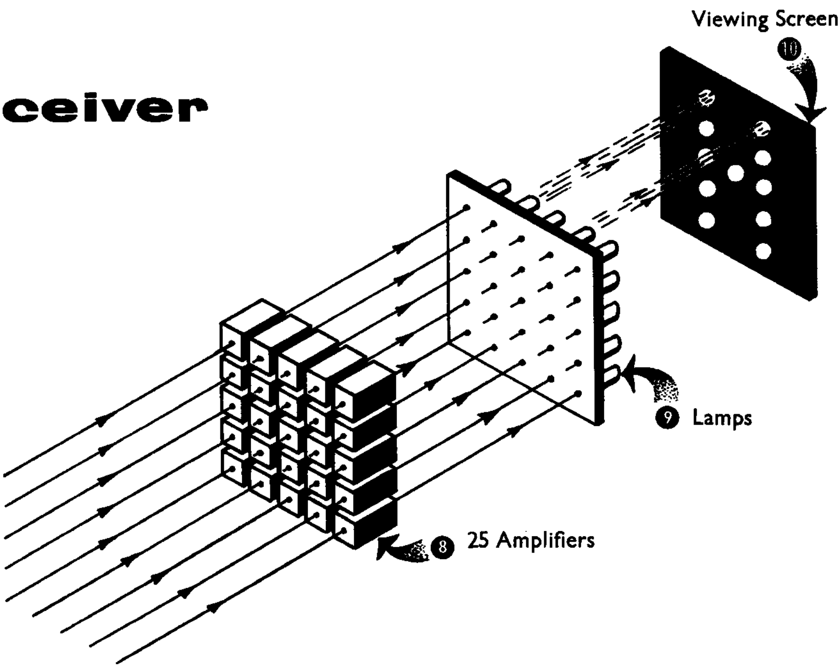
A "revised letter **H**" could, for example, be made up of (say) 100 areas of illumination, instead of only 25. This would imply a battery of something of the order of 500 photocells to "watch" the whole of the scene simultaneously, plus two banks of 500-odd amplifiers apiece, plus all the associated wiring, plus a battery of 500 lamps to throw their varying amounts of illumination on to that part of the viewing screen at which they were aimed. Quite an undertaking already . . .!

Yet even the improved letter **H** produced with the aid of all this paraphernalia would not approach in definition the coarsest of half-tones. To do even as much as that, many thousands of photocells, lamps, and their separate amplifiers and ancillary wiring would be required—and the bulk and cost of the resulting apparatus would be quite prohibitive.

For a TV system to be at all practical, something better is needed. You are now ready to learn about the methods which have been devised.

IMAGE-REPRODUCING SYSTEM

receiver



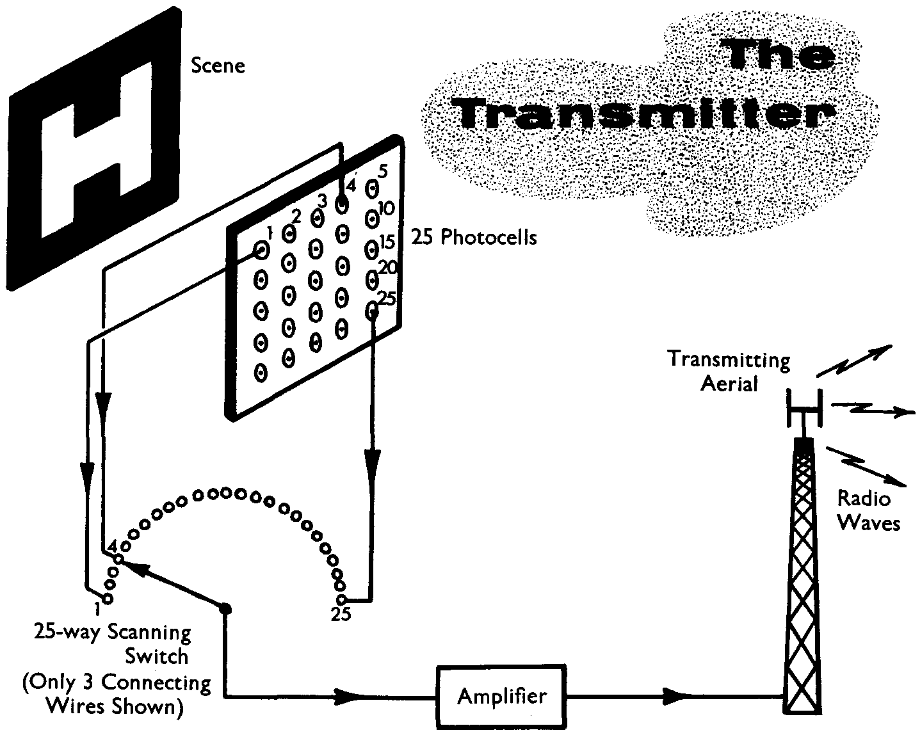
Sequential Scanning

The disadvantages of the primitive image-reproducing system you have just been looking at can be greatly reduced by making use of that peculiar property of the eye, persistence of vision. For if signals from the photocells in the camera, instead of being all transmitted simultaneously, can be transmitted *one after the other in very rapid succession indeed,* persistence of vision in an eye at the receiving end will create the illusion that the image there observed is really made up of a large number of simultaneously-produced areas of illumination.

The method which has been devised of transmitting the photocell signals in this very rapid succession is called **sequential scanning.** It is one of the basic principles on which all television systems work.

In the illustration below and opposite, every one of the 25 photocells in the transmitter is connected to a fast-moving *scanning switch* which picks up, one after the other, signals corresponding to the brightness level of the area of the scene which each individual photocell is "watching", and feeds it *to a common amplifier.* In the diagram, the switch is shown as collecting the signal corresponding to the light-output of Photocell No. 4, but it must be thought of as moving round very fast indeed.

Connections to the switch are arranged so that signals are collected from the photocells in sequence—top line first, from left to right; then down to the second line from left to right; and so on from top to bottom.



Sequential Scanning (*continued*)

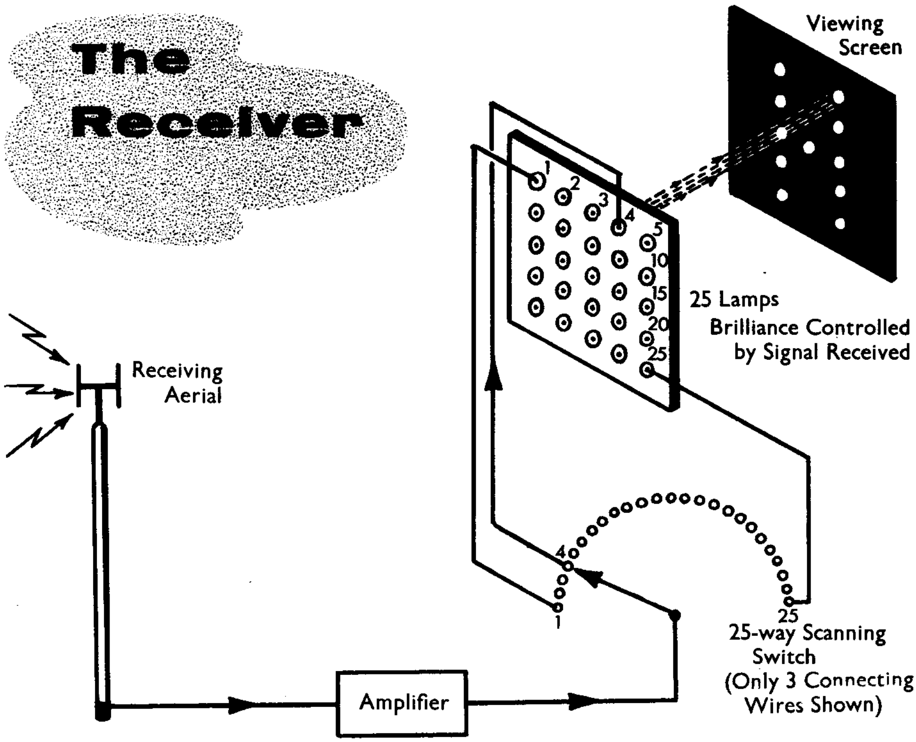
When the switch reaches the connection to Photocell No. 25 in the bottom right-hand corner, it flies back to No. 1 and begins the cycle all over again.

The output from the common amplifier is fed to an aerial, and transmitted as a modulated r.f. signal.

At the receiver, the signals picked up are amplified; and then connected to another switch, *synchronized with that in the transmitter*, which is in turn connected to a bank of 25 lamps arranged in the same geometrical pattern as the photocells. The brilliance of Lamp No. 4 is thus controlled by the signal produced by Photocell No. 4 and so on; and the area of the viewing screen which is illuminated by every lamp corresponds to the corresponding area of the transmitted scene.

One obvious advantage of this system over the more primitive one you have seen is that the equipment needed is very much reduced. Another is that normal radio-communication methods can be applied to the *single link* between transmitter and receiver. A third is that a large number of receivers can be served without serious problems of frequency bandwidth.

The key to the system is, of course, perfect synchronization of the scanning switch in the transmitter with the lamp selector switch in the receiver; for without this, much distortion of the reproduced image will occur. You will learn how this problem of synchronization is solved later on.



Flicker

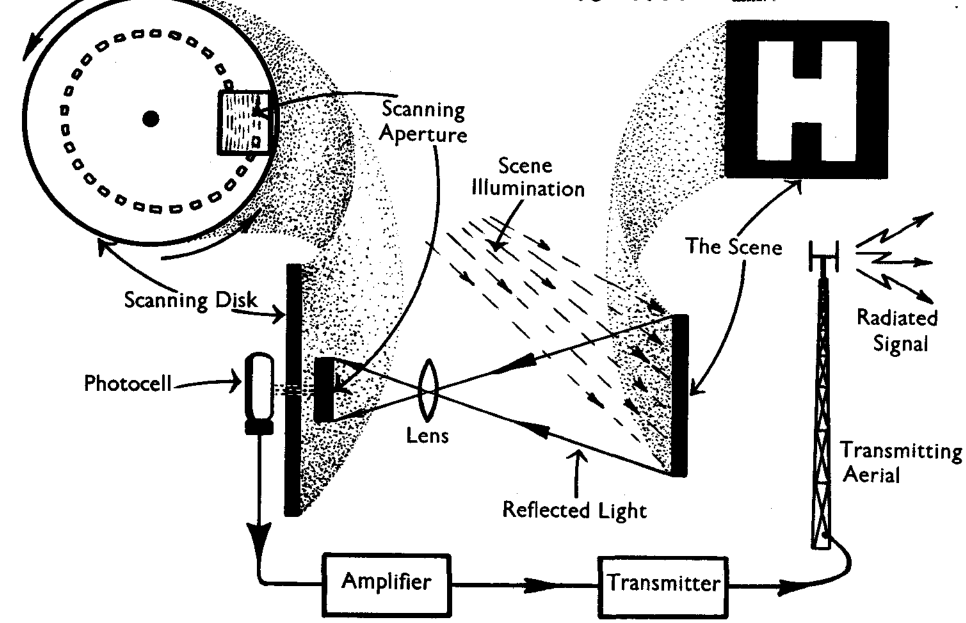
Provided that the rate of sequential scanning is high enough, the eye can be successfully "tricked", by reason of the persistence of its vision, into believing that a very rapidly renewed image on the viewing screen has in fact been there all the time. At the level of picture brilliance regarded as acceptable by the average TV viewer, the persistence of vision of the normal eye has been found to be about *one-fiftieth of a second*; so that the optical illusion necessary for any television system to work can be achieved if every individual area of the viewing screen can be illuminated by its appropriate lamp **not less than 50 times per second.**

At any rate of scanning lower than this, a phenomenon known as **flicker** develops. For flicker to be avoided in the primitive image-reproducing system, the entire bank of photocells would have to be completely scanned in time for the first (top left-hand) area to be re-scanned before the image of it had "died" in the viewing eye. If this rate of scan were not achieved, every succeeding image would impinge on an eye which was receiving no light at all; and such a succession of "light/no-light/light/no-light" would obviously produce in the viewing eye a tiresome flickering effect.

The achievement of a rate of scan high enough to overcome flicker was one of the major problems which faced the pioneers of TV. The earliest attempts involved the mounting of a number of differently-angled mirrors round a rotating shaft. One of the very earliest—the so-called "Mirror Drum Apparatus", designed in 1882, can be seen to this day in London's famous Science Museum in South Kensington.

Simplified arrangement of scanning–disk

The Transmitter



The Nipkow Disk

Another mechanical scanning device much used by the television pioneer John Logie Baird was the so-called **Nipkow Disk,** named after the Russian scientist, Paul Nipkow, who designed it in 1884 and patented it in Berlin.

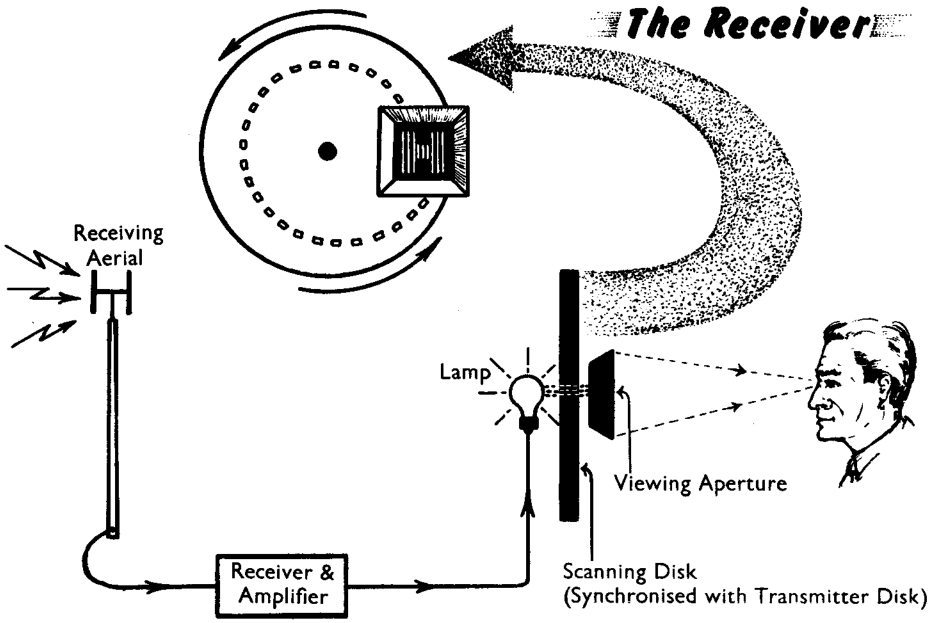
Nipkow's device consisted of an opaque disk, towards the periphery of which a number of small holes were drilled in the form of a single turn of a spiral. The scene to be televised was focused on to a small area on the circumference of the disk exactly wide enough to cover every hole in the spiral. Behind this narrow band was placed a photocell.

As the disk rotated, the outermost hole scanned a narrow strip of the *right-hand* side of the scene, doing so *from bottom to top*; and light reflected from scene elements in this strip reached the photocell. As soon as this hole had scanned to the top of the scene, the next hole took over in the bottom right-hand corner again, and scanned upwards on a line slightly to the left of the first.

This procedure was repeated with every hole in turn—the fact that each was slightly inset from its neighbour ensuring that the entire scene was scanned in every revolution of the disk.

Light striking the photocell was converted, in the normal way, into a series of electrical signals, each proportional to the tonal value of the scene element which produced it. These signals were then amplified and transmitted, one after the other, to the receiver. There they were arranged to control the brilliance of a lamp placed behind a second disk, identical to and synchronized with the first, which revolved so as to allow light from the lamp to pass through its holes on to the viewing screen. In this way, an image of the entire scene was built up.

method of television communication



Electronic Scanning

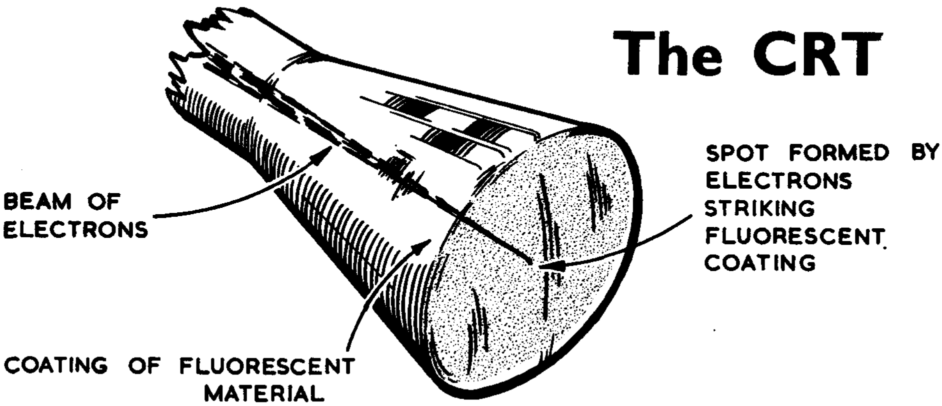
All the mechanical scanning systems just mentioned had three great disadvantages.

The first was that they made very uneconomical use of the amount of light illuminating the scene; for only a small fraction of the total light reflected from it ever reached the photocell. The result was that, for an acceptable level of light to get through to the photocell, extremely powerful lights had to be used. This often made things very unpleasant for the artists, whose make-up would often melt in the heat.

The second disadvantage was that, in order to get a picture of any reasonable definition, a great many peripheral holes were needed. This meant that the Nipkow disk had to be made very large; and then had to be made to rotate very fast to avoid flicker.

The third difficulty lay in achieving synchronization of the disk at the receiver end with that at the transmitter. Men still alive tell of how synchronization was achieved in the early days by the varying pressure of a thumb against the surface of a spinning disk!

As you will learn in the next few pages, one of the principal factors in determining the degree of definition of a televised picture is the *number of lines in the scanning period*. In early BBC transmissions, which had to make use of mechanical scanning systems for want of anything better, it was seldom more than 30. In a 30-line system, the number of elemental areas which it is possible to scan is about 1,000. This is not enough to provide an acceptable picture. Some totally different system was needed. It was found by using the cathode ray tube (CRT) which you learnt about in Section 11 of *Basic Electronics*, Part 5.



You know that the mass of an electron is almost infinitesimally small. It weighs, in fact, about 9×10^{-28} of a gramme—a figure which may mean more to you if you write it down as a decimal point followed by 27 noughts and then the figure 9! A body as small as that acquires almost no *momentum* (which is the product of its mass times its velocity) even when it is travelling exceedingly fast. It can therefore be made to move and to change direction at a speed immeasurably greater than is possible for any mechanical moving part—at a speed, in fact, comparable to that of light itself.

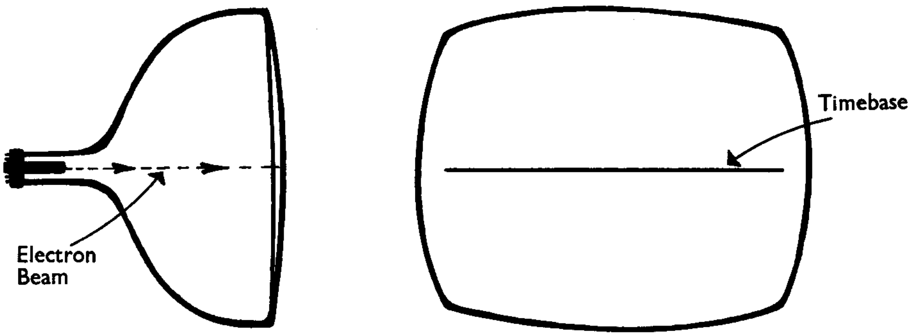
Electronic Scanning (*continued*)

In the electronic scanning system, the scene is observed by the TV camera, and projected on to a light-sensitive **target** contained in a special type of cathode-ray tube called a **camera tube.** You will learn in the next Section that this target is the effective equivalent of a large number of photocells set very close together.

A beam of electrons is then made to sweep across the target, very fast indeed, in a series of horizontal lines running from side to side, and from top to bottom. As the beam scans the various elemental areas of the target, a succession of electrical signals is produced, which are then amplified and transmitted to carry the picture information to the receiver.

At the receiver end, the received signals are made to control the intensity of a second electron beam, synchronized with the first, as it in turn scans the fluorescent surface of another CRT behind the viewing screen of the receiver.

This second CRT, with its fluorescent surface, is called the **picture tube.** Here is what it looks like—sideways on, and from in front.



THE PICTURE TUBE

You will remember from what you learnt in Part 5 of *Basic Electronics* that when the fluorescent screen of a CRT is bombarded by a stream of fast-moving electrons, the area of the screen struck by this beam gives off light; and that the more intense the beam, the greater the degree of fluorescence which will ensue.

You will also recall that means have been devised whereby the beam can be narrowed to a single spot at the moment it strikes the screen; and that if the beam is deflected very quickly across the screen, this spot will appear as a continuous line. Its apparent continuity is caused partly by the persistence of fluorescence (the "afterglow") in the CRT, and partly by persistence of vision in the human eye.

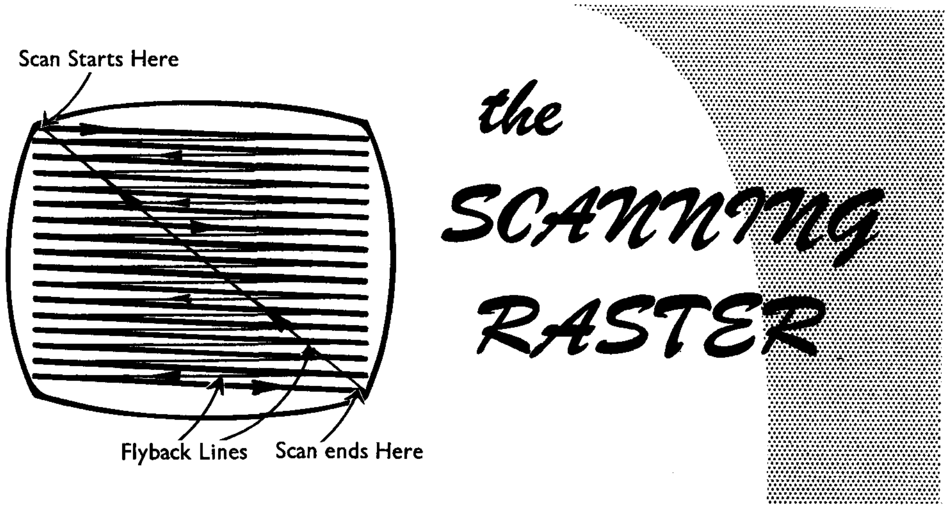
This continuous line of light moving across the CRT in the receiver of a television set is known as the **timebase,** the **trace,** or the **scan.**

The Scanning Raster in the Receiver

In the picture tube of the television receiver, the spot is made to move across the screen very rapidly indeed from left to right, and at the same time in a series of horizontal lines from top to bottom. When it reaches the bottom right-hand corner of the screen, it is returned very quickly to the top left-hand corner, and the scanning cycle is repeated.

If this sequence is repeated fast enough (about 50 times per second) the whole screen will have been scanned, and the fluorescence of the top line will have been renewed by a second scan before the light of the first scan has had time to fade in the eye of the viewer.

The image presented will be that of a series of parallel lines of light running very close together almost horizontally across the screen. This presentation—parallel lines of light having no picture content—is known as the **scanning raster.**



In the picture of the raster the number of lines has been much reduced, for greater clarity. Note that during the unwanted (right-to-left, and bottom-to-top) movement of the spot—known as **flyback periods**—the electron beam is in practice suppressed altogether, and produces no trace.

You will see that the motion of the spot when tracing out the raster is very like the movement of your eye as you read this printed page. Your eye starts at the left-hand top corner of the page, and scans the first line from left to right, *fairly slowly*. It then moves back *very quickly* to the beginning of the second line at the left of the page, "flying back" relatively very fast because it has no reading to do on the way. It then scans the second line as before. The sequence is repeated line by line down the page, until the last word in the bottom-right-hand corner is reached.

One further point may look obvious, but you will see its importance later on. The depth of the type-area on this page is about a third greater than its width. But your eye will take much more than a third longer to scan the whole page than it will to scan a single line of it. In other words, its "page-scanning rate" is much longer than its "line-scanning rate".

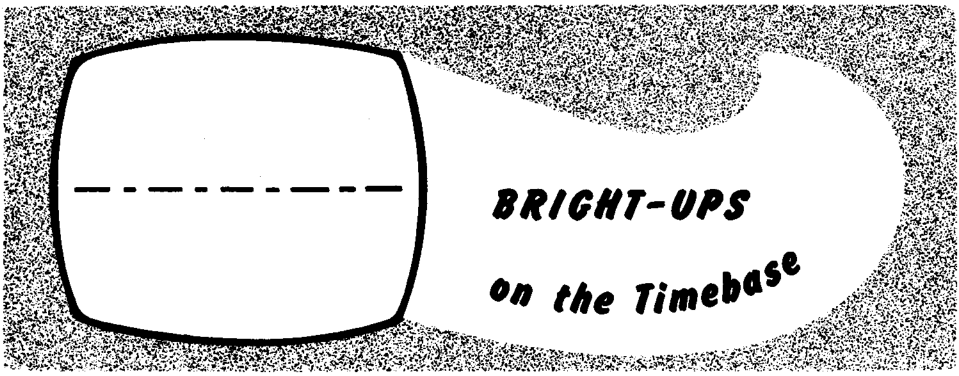
Modulating the Raster

You have just seen that the raster, in its normal state, produces only a series of parallel lines of light running horizontally across the screen, and presents no picture detail at all. But you also know that the intensity of the electron beam which produces the raster can be varied by the strength of the signals received from the transmitter.

When this variation of signal strength occurs during the movement of the beam across the screen, the brilliance of the spot varies also—from very bright to almost dark, or to any degree of brightness in between—with the changes in brightness succeeding one another with enormous rapidity.

It is by building up an enormous number of rapidly-varying but controlled changes of bright-up, accurately synchronized with the scan at the transmitter, that the CRT in the television receiver can be made to trace out across the screen a picture of the image transmitted.

In the illustration below, it is assumed that the intensity of the electron beam has been increased for nine *regularly-spaced* long-and-short periods during a single trace. The resultant scan will be punctuated by nine *regularly-spaced* long-and-short *bright-ups*, as they are called. (In an actual picture, of course, bright-ups will never be regularly-spaced longs-and-shorts, but will vary in duration and intensity with the tonal content of the scene.)



A Difficulty of Bandwidth

You might well think, after reading the above, that it was normal TV practice to make the electron beam scan the screen of the picture tube (and the corresponding beam scan the target in the camera tube) *in a consecutive series of horizontal lines from top to bottom.*

It is indeed possible to produce a quite satisfactory image by this method; but in practice there arises a difficulty.

You know that, if flicker is to be avoided, the rate at which a series of images must be presented to the eye is of the order of 50 times per second. So if flicker is to be avoided on the TV picture tube, *the complete picture* must be presented and re-presented to the eye at a rate no lower than that.

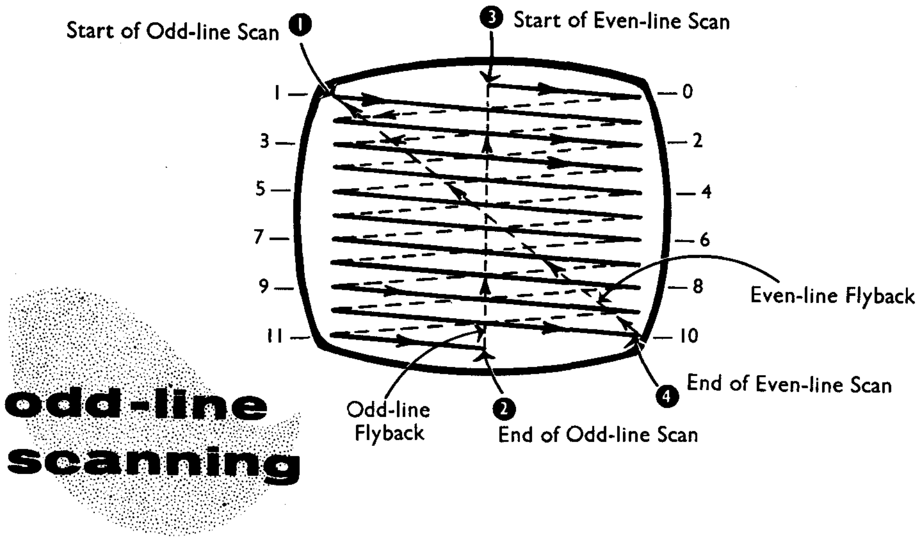
But, as you will see later on, a picture-repetition frequency as high as 50 per second would call for a very wide frequency bandwith for the transmission of the video signal, and would therefore greatly restrict the number of channels which could be accommodated within a given frequency band.

Interlaced Scanning

An ingenious way has been found of getting round the difficulty described on the last page. It is called **interlaced scanning.**

Instead of the target in the camera tube and the screen in the picture tube being scanned in consecutive lines, the beam is first made to scan *all the odd-numbered lines* in their proper order—that is to say, Lines 1, 3, 5, 7, 9, etc., down to the bottom line of all. It then scans all the even-numbered lines—2, 4, 6, 8, 10 and so on—down to the end of the penultimate line of the raster. From there, it flies back to the beginning of Line 1, and the process is repeated.

For reasons which you will see later on, the beam is not allowed to complete the bottom (odd-numbered) line before starting to scan the topmost even-numbered line. Instead, it is stopped half-way along the bottom line and made to fly more or less vertically upwards (with its trace of course suppressed) to half-way along the topmost even-numbered line, to resume its horizontal trace from that point.



This means, of course, that *two* vertical sweeps of the raster have to be made by the electron beam to produce *one* complete picture on the screen. The first half-picture is produced by the scanning of odd-numbered lines only; the second half-picture is produced by the scanning of even-numbered lines only. This second half-picture is then superimposed on the first, to make up the complete picture.

You will see the advantages of this technique on the next page.

Every half-picture presentation is nowadays called a **field** (*it used to be called a "frame" in Britain; but this term has now been officially superseded*). Every whole-picture presentation is called a **picture.**

The number of half-pictures presented in every second is called the **field frequency,** and the number of complete pictures presented in every second is called the **picture frequency.** Since *two* fields equal *one* picture, the field frequency is always double the picture frequency.

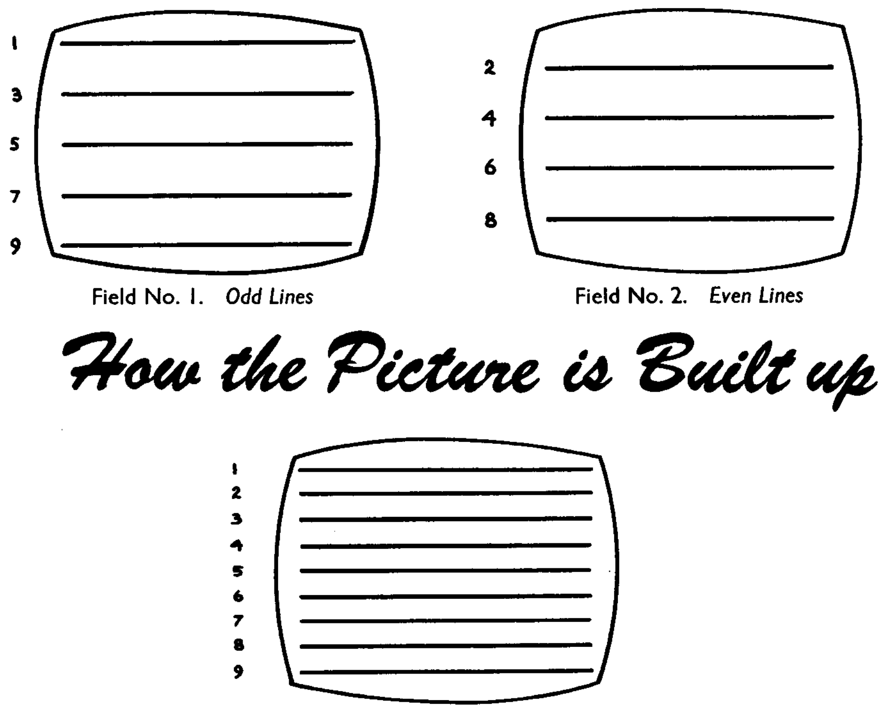
Interlaced Scanning (*continued*)

You know that a sequence of images must be presented to the eye at the rate of about 50 per second if flicker is to be avoided; but you have seen that a picture frequency as high as 50 per second presents problems of bandwidth. How does the technique of interlaced scanning help to get over this difficulty?

You know that the two fields making up one picture are superimposed on one another very quickly. You also know that the fluorescent coating on a picture tube screen has afterglow. And you will have realized, no doubt, that the vertical distance between two adjacent lines of a scan is optically tiny.

The outcome of these three factors is that any line *not* being scanned at a given moment is closely sandwiched in between two lines, above and below it, which *are* being scanned at that moment. The even-numbered lines of Field No. 2 thus carry on the work of presenting a continuous picture which was begun by the odd-numbered lines of Field No. 1; and effective continuity of vision is achieved when only **25** scans of Field No. 1 plus **25** scans of Field No. 2 are completed in every second.

The result is that a continuous picture without flicker can be achieved by means of interlaced scanning *at a picture frequency of only* 25 *per second.*

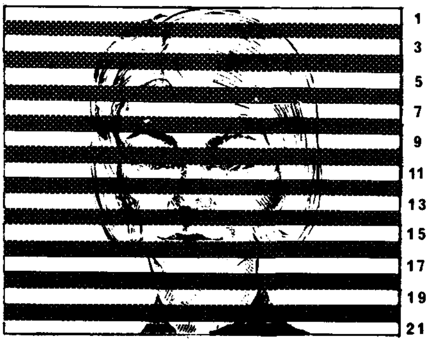


Field No. 1. *Odd Lines* Field No. 2. *Even Lines*

How the Picture is Built up

Field 1 + Field 2. *Complete Picture*

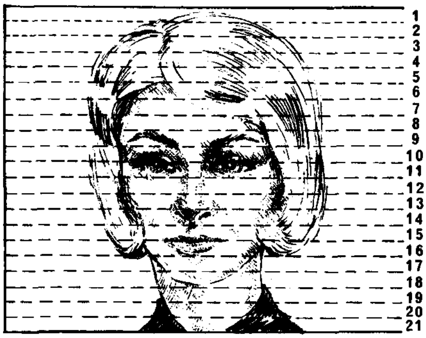
ODD-LINE INTERLACING



25 Repetitions per Second of this ODD-LINE SCAN **PLUS** 25 Repetitions per Second of this .. EVEN-LINE SCAN

PRODUCE

50 Images per Second and so give



25 Repetitions per Second of this ..
COMPLETE PICTURE WITHOUT FLICKER

Scanning Frequencies

It is possible to design TV systems making use of many different numbers of scanning lines per picture. As you probably know, both British television networks at present use a system based on 405 lines to the picture—a number chosen in the early days of TV back in 1936.

In the course of the next few years, however, it is planned to change over gradually to a system based on **625 lines to the picture**—as recommended by an internationally recognized body, the *Comité Consultatif International des Radiocommunications* (CCIR), as long ago as 1950. The change-over has already begun with the introduction of "BBC 2".

The number of lines currently used in some national TV systems is:

405	**United Kingdom, Eire.**
525	**U.S.A., Canada, Mexico, Cuba, Bermuda, Puerto Rico, Haiti, Trinidad, Costa Rica, Panama, Colombia, Peru, Brazil, Uruguay, Hawaii, Japan, Korea, Philippines, Cambodia, Thailand, Saudi Arabia, Kuwait and Iran.**
625	**United Kingdom, Eire, France, Belgium, Holland, East & West Germany, Norway, Sweden, Finland, Denmark, Poland, Czechoslovakia, Switzerland, Austria, Hungary, U.S.S.R., Spain, Portugal, Italy, Yugoslavia, Turkey, Lebanon, Syria, Cyprus, Egypt, Morocco, Nigeria, Ghana, Kenya, Rhodesia, Iraq, China, Australia, New Zealand, Venezuela and Argentina.**
819	**System becoming obsolescent, but has recently been in use in France, Belgium, Luxembourg, Monaco, Algeria, Tunisia and the Ivory Coast.**

Note that every system used contains an *odd number of lines*. An odd number of lines in the picture means that there must be a whole number of lines *plus one half-line* in every field. Thus the 405-line system gives $202\frac{1}{2}$ lines per field; the 625-line gives $312\frac{1}{2}$; and so on. As you will see in detail later on, the purpose of this is to make interlacing automatic.

Whatever the number of lines a system uses, *the rate* at which the lines are produced, or presented, is termed the **line scanning frequency** (sometimes the **horizontal scanning frequency**). If one complete picture consists of 405 lines and takes one twenty-fifth of a second to scan, it means that lines are being produced or presented at a rate of $(405 \times 25 =)$ 10,125 per second.

The time-base generators which govern both line and field frequencies are (as you will discover) basically oscillators, and oscillators work at so-many-cycles-per-second. It is therefore customary to express line scanning frequencies in "Hertz", the unit of measurement now used for cycles-per-second. Thus the line scanning frequency of a 625-line system is always said to be $(625 \times 25 =)$ **15,625 Hz.**

Line Scanning Periods

The time taken by the electron beam to scan any one complete line of a field is called the **line scan period** (or sometimes the **horizontal scan period**). It is calculated as follows.

If 405 lines take one twenty-fifth of a second to be produced or presented, one line must take $\frac{1}{405 \times 25}$ seconds. This works out at 0·0000988 seconds, or 98·8 microseconds (one μs being, as you will remember, one-millionth of a second). Since it is in practice impossible to avoid small variations in the field frequency, the line scan period for the 405-line system is generally taken to be a round **100 microseconds.**

The line scan period for the 625-line system works out at **64 microseconds.** Since there are 312·5 lines in a single field in this system, and since it takes 64 μs to scan a single line, it follows that a whole field takes 20,000 μs to scan. In the 405-line system, there are 202·5 lines in a field, and each is scanned in about 100 μs. Once again, the entire field is scanned in approximately the same time of 20,000 μs.

In neither system, therefore, is the horizontal or line scan rate less than some 200 times greater than the vertical or field scan rate. In the 625-line system, indeed, it is over 300 times greater. Contrast this with the time it takes your eye to scan a line of this page, and then the page itself.

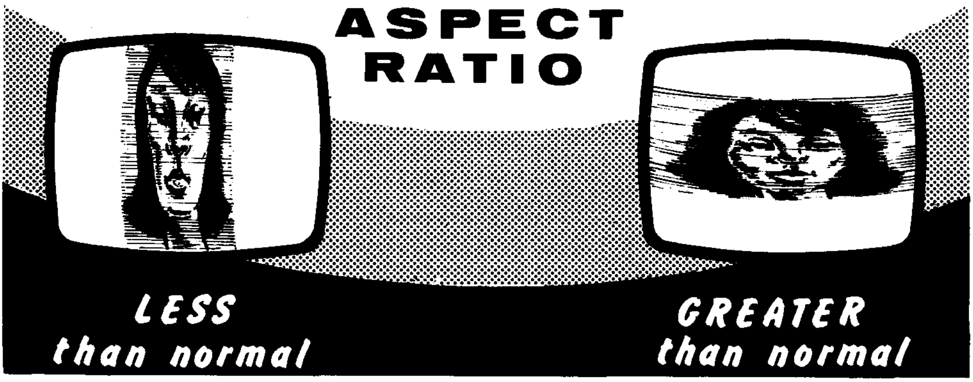
Note that the 20,000 μs which, in both systems, it takes to scan a field is equal to $\frac{1}{50}$th of a second. This ties in with what you already know—namely, that 50 fields are presented in every second.

Aspect Ratio

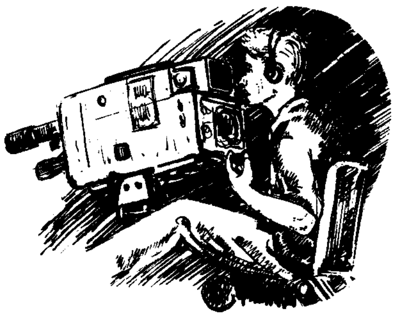
The ratio of picture width to picture height on a TV screen is known as the *aspect ratio*, and is standardized in most systems throughout the world at 4 : 3.

Many years ago, when suitable dimensions for a TV picture were being discussed, it was decided to make the aspect ratio the same as that of the then conventional cinema film—with the idea that the latter could be televised with the minimum of adjustment to either picture tube or camera. It has remained the same ever since.

The true aspect ratio of a televised picture is determined in the camera. So although you can adjust the *Height* and *Width* controls on your TV receiver to give almost any aspect ratio you like, the picture will not appear natural if the ratio is other than 4 : 3.



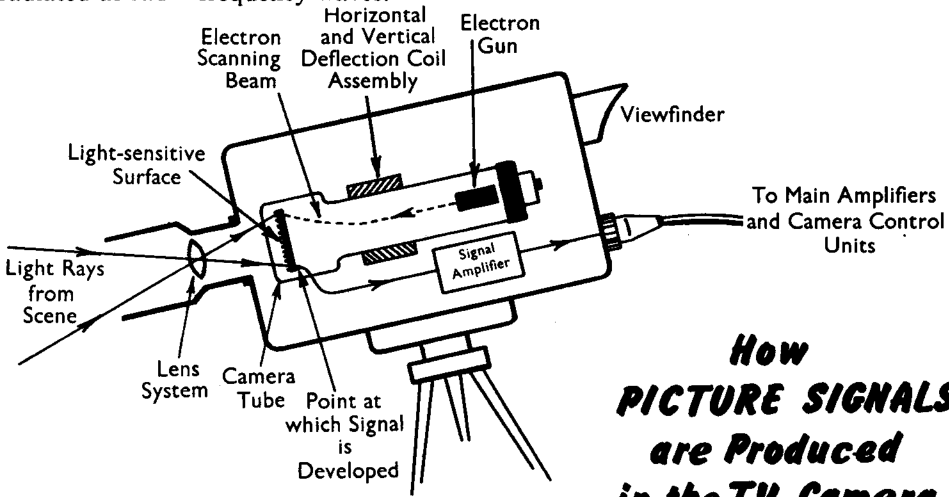
§ 4: THE PICTURE SIGNAL



The most important piece of equipment in the television studio is the TV camera; for it is there that the picture signal originates. This remarkable electronic eye, silent and invisible to the viewer, is continually watching every movement, every change of shape and every tonal content of the scene, and converting what it sees into a complex stream of electrical signals so that the scene may be reproduced, almost instantaneously, many miles away in millions of homes.

To perform this feat, the TV camera makes use of a special type of cathode-ray tube called a **camera tube,** which transforms the image to be televised into an equivalent picture composed of millions of tiny individual electric charges. This charge-image pattern is then scanned from top to bottom in a series of horizontal lines by a narrow beam of electrons which "reads" the electrical information contained in the pattern and converts it into a consecutive series of electrical signals, each proportional in amplitude to the brightness of a particular section of the original image.

These picture signals, representing the tonal content of the image, occur one after another rather like the information presented on a ticker-tape machine. After amplification (and mixing, for reasons which you will shortly see, with synchronizing pulses), the picture signals, together with the separate sound signals, are carried by land line or by SHF microwave link to the transmitting station, where they are radiated as radio-frequency waves.



How PICTURE SIGNALS are Produced in the TV Camera

Television cameras, like photographic cameras, contain an optical lens system which collects the light from the scene and focuses it on to a light-sensitive surface.

In the photographic camera, this surface is usually a section of a spool of film. In the TV camera, it is a specially coated surface inside the camera tube which is known as a **photo-cathode,** or (in some types of camera tube) as a **mosaic.** This photo-cathode itself forms part of a **target** assembly.

Secondary Emission

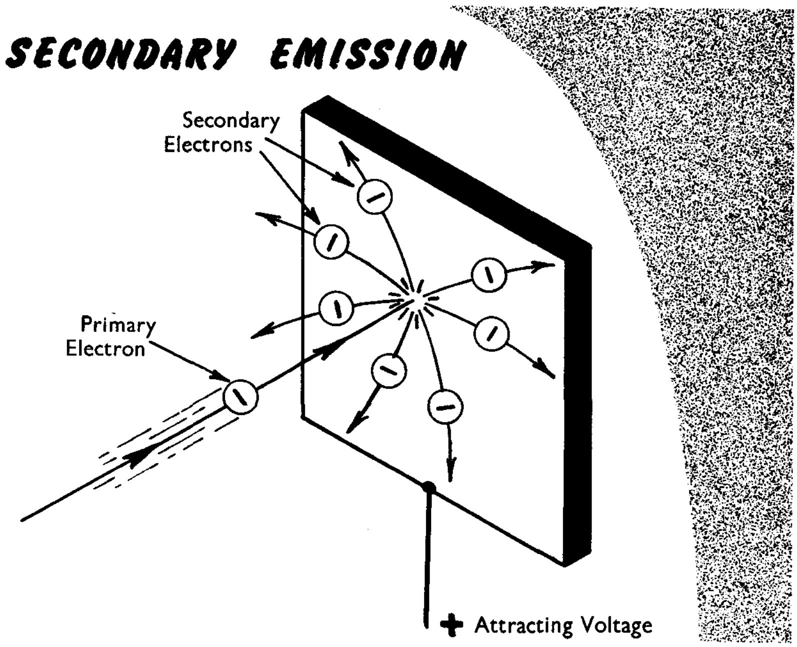
Before studying the behaviour of the light-sensitive target in the television camera, you must first understand something about a phenomenon known as **secondary emission.** This phenomenon is similar to the photo-electric effect described in an earlier Section in that it concerns the emission of electrons from a surface. It differs from photo-electricity in that it relies, not on light to cause the emission of electrons from the surface, but on the impact on that surface of a stream of electrons from an outside source.

When the surface, usually of a conducting material, is bombarded by electrons exceeding a certain velocity, the impacts cause additional electrons to be released from the surface. These are known as **secondary electrons.** The number of secondary electrons released per impacting "primary" electron is dependent on the velocity of the primaries, and on the composition of the material being bombarded.

The number of secondaries released for every primary electron impact is known as the **secondary emission ratio** of the material. It is typically between 2 and 10. One of the most used secondary-emissive materials is caesiated silver (*i.e.* silver oxide coated with caesium). This material, in addition to having very efficient photo-electric performance, also has the comparatively high secondary emission ratio of 7.

The diagram below shows what happens when a single primary electron is attracted towards the surface of a secondary-emissive material. Provided that the positive attracting voltage is high enough, the electron will acquire sufficient velocity, and therefore sufficient kinetic energy, to knock secondary electrons from the surface of the material.

In the diagram, seven secondaries are shown as being released by the impact of the single primary electron. The secondary emission ratio of the material is therefore 7.

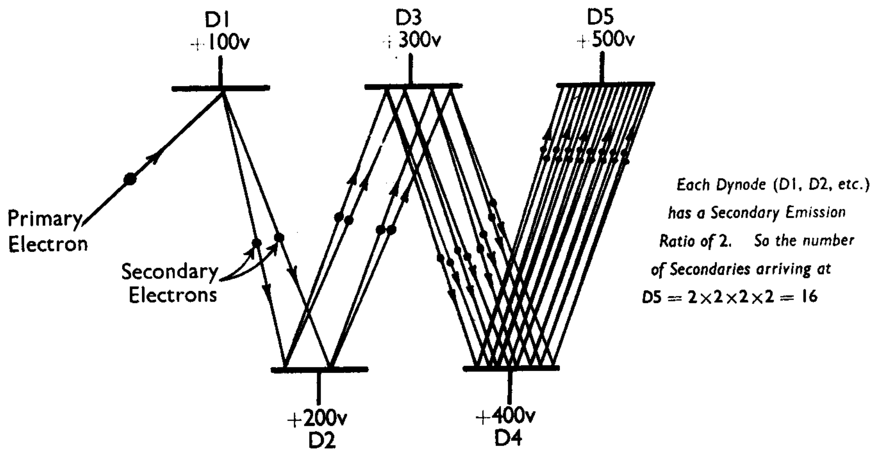


The Photo-Multiplier

An important electronic device which relies on secondary emission for its operation is the **electron multiplier.** This is a current-amplifying device which is capable of enormous amplification—often greater than one million times.

The principle on which it works is as follows. Primary electrons, originating from some thermionic or photo-electric source, are attracted towards a positively polarized secondary-emissive surface, from which secondary electrons are released when they strike it. These secondaries are then attracted towards a second positively-polarized secondary-emissive surface, which is held at a potential higher than that of the first. Thus if seven secondaries are released from the first surface, $7 \times 7 = 49$ secondaries will be released from the second surface—and so on for as many additional surfaces as you care to employ.

The photo-emissive surfaces in an electron multiplier are called **dynodes.** In a 5-stage electron multiplier in which each of the five dynodes has a secondary-emission ratio of 7, the overall gain of the device will be theoretically $7 \times 7 \times 7 \times 7 \times 7 \doteq 16{,}800$. In practice, however, the overall gain will be appreciably less, for perfect collection and emission is never realized in practice.



How the ELECTRON MULTIPLIER works

Electron multiplier assemblies are often used in conjunction with photo-electric surfaces to provide large amplification of the tiny currents which are produced by photo-electrons released from the light-sensitive surface.

In such an arrangement, a transparent light-sensitive surface such as a photo-cathode is placed at one end of an evacuated glass tube, with the electron multiplier immediately behind it. When the photo-cathode is exposed to light, it releases from its rear surface electrons which are then directed towards the first stage of the electron multiplier.

Such an assembly (photo-cathode plus electron multiplier) is called a **photo-multiplier.** A much-used TV camera tube called the *Image Orthicon* works, as you will see, on a principle very similar to that of the photo-multiplier.

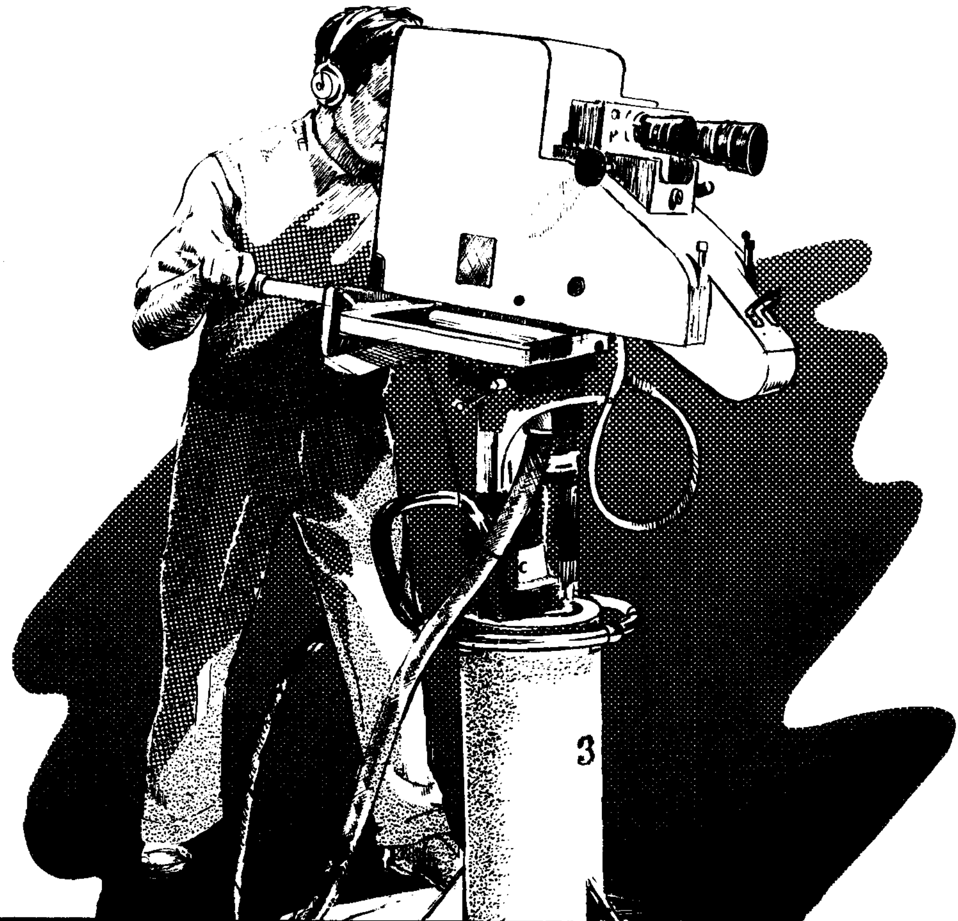
The Television Camera

Since the beginning of electronic scanning, many types of camera tube have been designed, some better suited than others for a particular application such as studio use, outside broadcasting, etc.; but of them all the most widely used over the years have been the **Iconoscope,** the **Image Orthicon** and the **Vidicon.**

The Iconoscope

The Iconoscope camera tube, invented in 1925 by the Russian-American scientist Vladimir Zworykin, though now obsolete, has played an important part in the history of television. A British development of the Iconoscope known as the *Standard Emitron* was in regular use by the BBC over the period 1936–1939, and for a short time after the end of World War II. A camera tube of this type was used to televise the Coronation procession of King George VI in 1937—the very successful first "live" outside TV broadcast by the BBC.

Although it is now largely superseded by camera tubes of more recent design, the principle of operation of the Iconoscope makes a good starting-point for your study of the television camera.



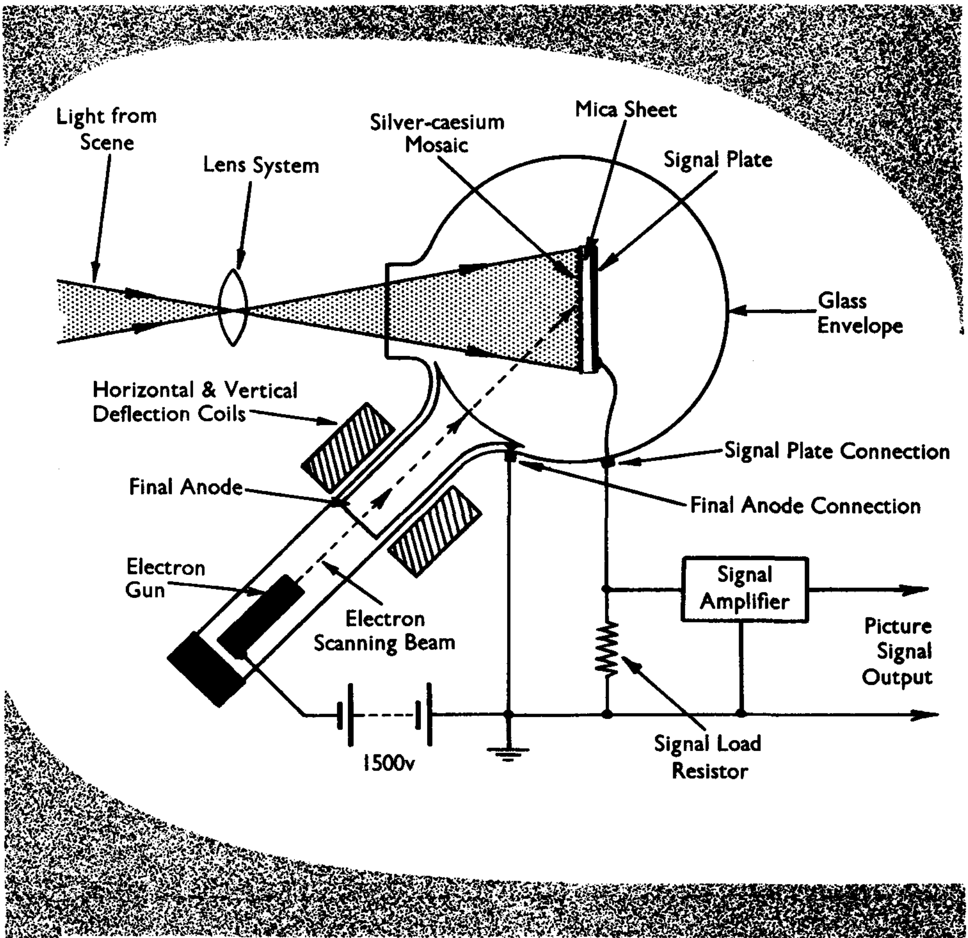
The Standard Emitron Camera

The Iconoscope—Construction

The envelope of the iconoscope shown in the diagram below consists of a spherical glass bulb about 200 mm in diameter. To it is attached a side tube similar in appearance to the neck of a conventional cathode-ray tube. This houses an **electron gun** similar in general construction to the type described on page 5.101 of *Basic Electronics*, but rather more complex so as to minimize the danger of secondary emission within the gun itself.

Round the inside of the neck of this side tube there is deposited a thin film of conducting material, electrically connected to earth through a terminal on the outside of the glass bulb. This is called the **final anode.**

The light from the scene is collected and focused by an optical lens system on to the light-sensitive surface of a rectangular target suspended in the centre of the glass bulb. The surface of the bulb through which the light passes **(the optical window)** is made flat so as to prevent geometrical distortion of the light image on the target.



THE ICONOSCOPE – *Standard Emitron Type*

The Iconoscope—Construction *(continued)*

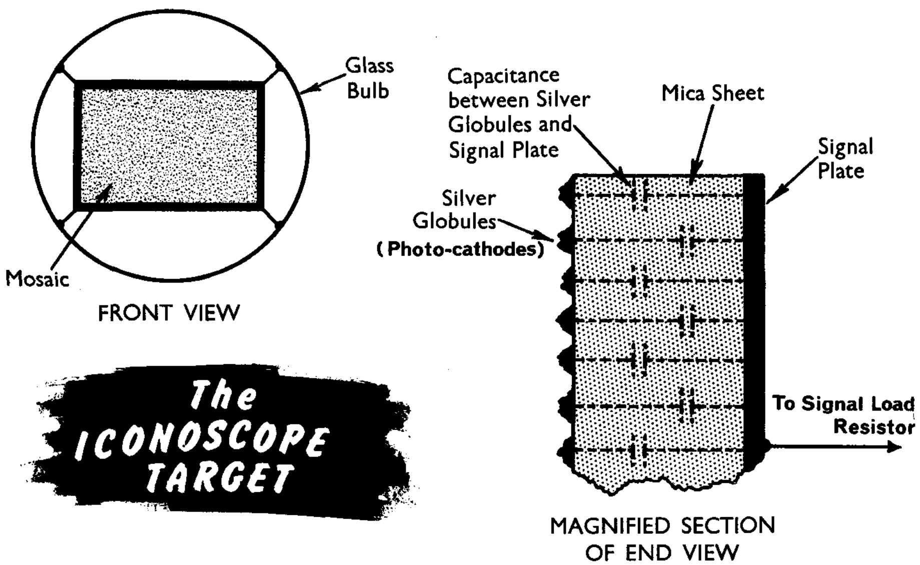
The target itself consists of a very thin sheet of mica covered on one side with millions of tiny globules of oxidized silver coated with a thin film of caesium. Since, as you know, caesiated silver possesses the property of giving off electrons when illuminated, every globule on the target forms a tiny light-sensitive island. Every island is electrically insulated from its neighbour by the surface of the mica sheet.

This side of the target is called the **mosaic.**

On the other side of the thin mica sheet is a metallic coating called the **signal plate.** By reason of the insulating properties of the mica, there exists a small capacitance between every silver globule on the mosaic on one side of the target, and the signal plate on the other. The target thus becomes an assembly of millions of tiny capacitances set very close together, each sharing the same dielectric (the mica) and each having one of its electrodes (the signal plate) in common with all the others.

As soon as the beam from the electron gun starts to scan the mosaic, the silver globules acquire a small overall negative polarity with respect to the final anode. What happens (to cut a fairly involved action short) is that the beam knocks a great many electrons out of the photo-sensitive material of which the globules are composed, by a process of secondary emission. Many of these liberated electrons are collected by the final anode and flow to earth. The remainder fall back more or less evenly on to the surface of the mosaic, thus leaving it slightly negative with respect to the final anode.

In this way, every one of the millions of silver globules on the mosaic becomes the photo-cathode of a tiny photocell whose common anode is the final anode itself.



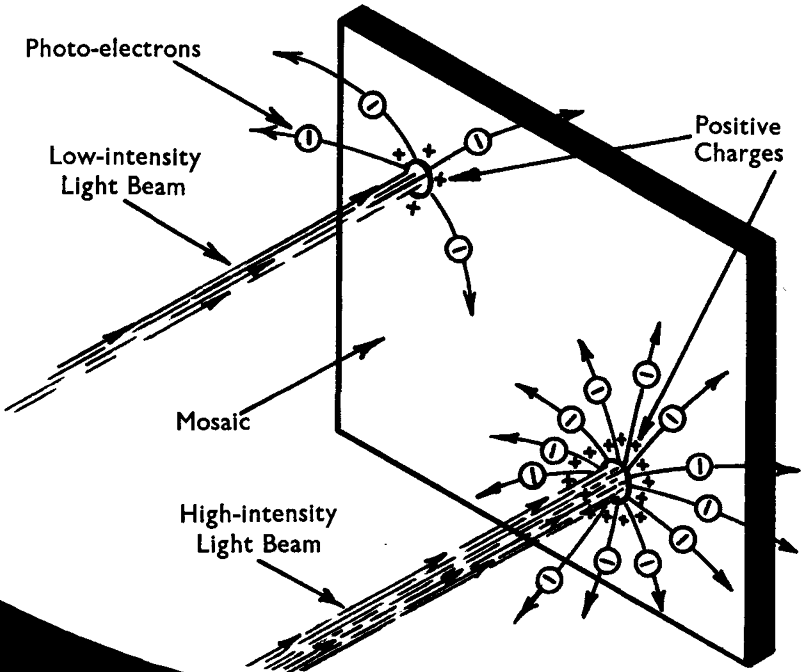
The Iconoscope—Operation

Light reflected or originating from the scene to be televised is collected by means of the lens system on the front of the camera, and focused on to the mosaic surface of the target. The millions of tiny photocells making up the mosaic are affected by the light from the scene. More electrons are emitted from their photo-cathodes, and are collected by the final anode.

The actual number of electrons emitted from any cell depends on the amount of light falling on it. In brightly illuminated regions of the mosaic, cell emission will be quite large; in darker regions it will be considerably less. If the illumination of the mosaic were uniform, as it would be if the scene consisted of a plain white surface, the emission from every photocell would be identical.

You know from your study of *Basic Electricity* that whenever electrons are released from a body, that body becomes less negatively charged. So the light from the scene falling on to the mosaic causes every photo-cathode to acquire a more positive charge proportional to the amount of light falling on it.

In other words, the brighter the light, the larger the positive charge on that part of the mosaic on which the light falls.

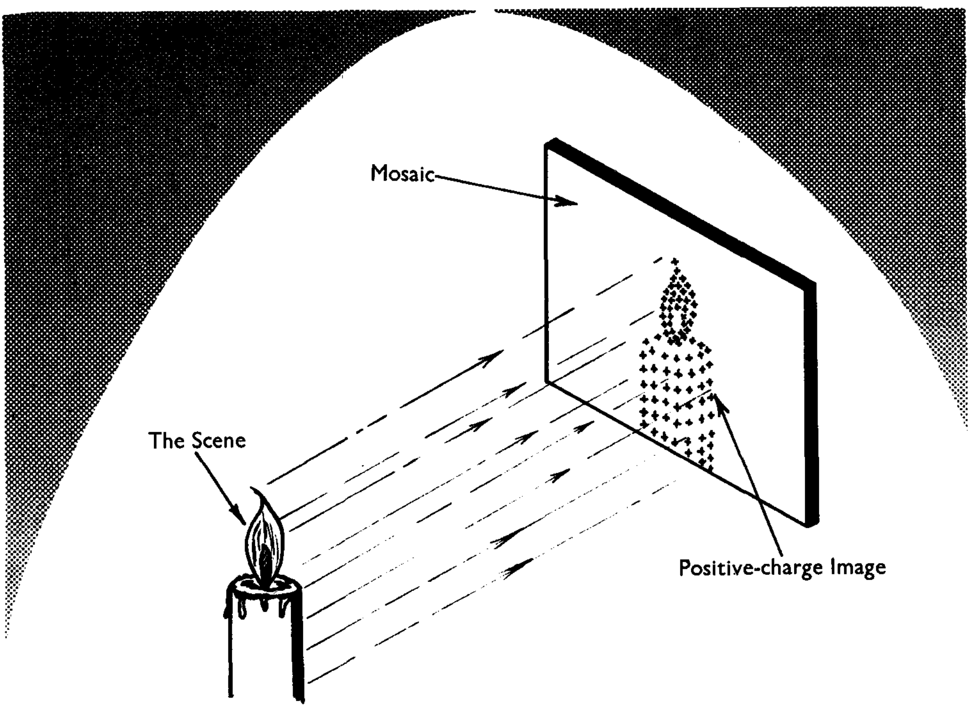


How Light from the Scene . . . .
. . .Strikes the Mosaic

The Iconoscope—Operation (*continued*)

The "picture" of the scene appearing on the mosaic thus consists of a pattern of electrical charges (some large, some small) stored in millions of tiny capacitances. The longer the light image remains on the mosaic, the longer will the capacitances have to charge up. Ideally, each should be allowed sufficient time to charge to a voltage corresponding to the saturation of its associated photocell on the mosaic.

The charges stored in the capacitances are prevented from leaking to one another (and so destroying the charge-image) by the very high lateral resistivity of the mica sheet. It has been known for a charge-image to remain stored on a mosaic for several hours without appreciable leakage occurring.



How the POSITIVE CHARGE IMAGE is Created

The next problem is to convert the capacitive charge-image stored on the target into a useful electrical signal.

Again the electron beam is made to sweep across the mosaic from top to bottom, in a series of horizontal lines closely spaced one below the other. As it does so, it "reads off" the picture information stored on the target by converting the optical image focused there by the camera lens into a train of electrical signals, each representing a very tiny part of the scene.

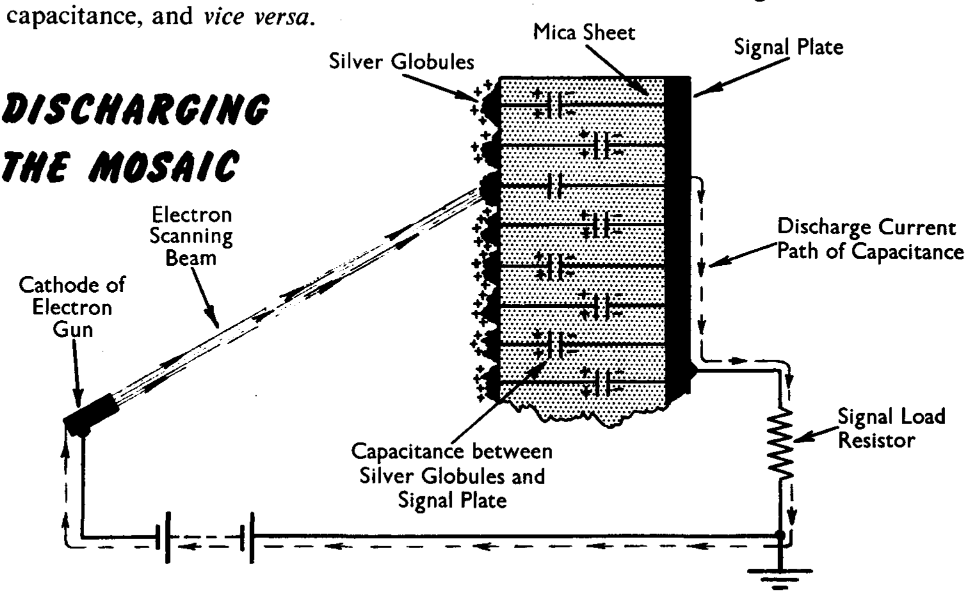
This train of signals is the **picture signal.** You must now see how it is created from the charge image on the mosaic.

The Iconoscope—Operation (*continued*)

What happens is that as the beam sweeps across the mosaic, it provides a discharge path for all the tiny capacitances in turn as it touches their associated photo-cathodes. This discharge path is the beam itself, the cathode supply, the signal load resistor, and the signal plate of the target—this latter being, you will recall, a common electrode for all the tiny capacitances formed with the mosaic.

As every photo-cathode in turn is touched by the beam, the positive charge created on it by light from the scene is neutralized by electrons from the beam. The associated capacitance discharges through the signal plate and the *signal load resistor*. When the more positive areas created on the mosaic by brighter areas of the scene are touched by the beam, more electrons flow to neutralize the charge on the relevant capacitance, and *vice versa*.

DISCHARGING THE MOSAIC



As the discharge currents flow through the signal load resistor, a sequence of voltage pulses is developed across it proportional to the amount of positive charge on the particular area of the charge image which is being scanned at that moment. In this way, the image of the scene focused by the camera lens on to the mosaic is converted into a series of electrical signals following each other in very rapid succession, each representing in ordered sequence a tiny part of the scene.

The little capacitances through the target, once discharged, are immediately re-charged by light from the scene. There exists, therefore, an obvious danger of their being discharged once more by the beam as it passes over them during its fly-backs to the beginning of a new sweep or to the start of a new field. The result would of course be a meaningless jumble of signals reaching the output.

To prevent this, there is applied to one of the electrodes of the camera tube at the end of every line and field scanning period a voltage of appropriate polarity called a **blanking pulse.** The amplitude of this pulse (it comes from a *control unit* in the studio) is such that it completely suppresses the beam during its fly-back periods. No unwanted signals are therefore touched off as the beam returns to the start of a new line or field.

The Iconoscope—Sensitivity

You will recall that in the mechanical scanning systems described earlier (the Nipkow disk, for example), the photocell was exposed to the light originating from each elemental area of the scene for only so long as it took the disk to scan that area. This meant that the useful light received was only a small fraction of the light available during the whole scanning period. The system was therefore very insensitive.

In the Iconoscope, the photocells of the mosaic target are continuously exposed to the light from every elemental area for the whole of the scanning period; and charges accumulate for that period in the mosaic/signal-plate capacitances. The total charge accumulated is thus many times greater, and it is this which accounts for the enormous difference in sensitivity between the Iconoscope camera tube and the Nipkow disk.

In theory, this difference in sensitivity is as much as 100,000 : 1; but in practice the sensitivity figure for most types of tube working on the charge-storage principle is considerably less than the theoretical maximum. In the Iconoscope tube the overall efficiency is, for various reasons, as low as 6%—though even so its sensitivity is still very much greater than that of any mechanical scanner.

The Iconoscope—Resolution of Detail

In the primitive 25-cell image-reproducing system described earlier in this book, you saw that the smallest detail of the scene capable of being resolved by the transmitter was the area of the scene "viewed" by a single photocell. In the Iconoscope camera tube, as you have seen, the mosaic consists of a very large number of tiny photocells, each of which represents the smallest detail of the scene capable of being resolved (*i.e.*, an elemental area). You might think, therefore, that, if the diameter of the scanning beam was made no larger than the area of a representative photocell on the mosaic, the Iconoscope would be capable of an enormously high degree of resolution.

In practice, however, difficulties of manufacture cause unavoidable differences in size to exist between the individual particles of silver—with the result that there is uneven sensitivity between photocells. If the scanning spot were to be made no larger than an individual photocell, therefore, every single cell ("large" and "small" alike) would be sampled by the beam, and the variations in sensitivity would cause the image to take on a "grainy" appearance.

To prevent this happening, the structure of the mosaic—that is to say, the number of silver particles on every square inch of its surface—is deliberately made much finer than it need be. The result is that *at least ten* photocells are covered at any one time by the scanning spot as it moves across the mosaic. In this way, differences in sensitivity of the photocells are averaged out; and a uniform degree of sensitivity is achieved.

The actual size of the scanning spot is determined by the size of the target and by the number of scanning lines in every complete picture. It is usually arranged for the diameter of the spot to be made *equal to the spacing between adjacent lines.* When this is done, the discharge of the mosaic is uniform and complete during every scan. Another advantage is that a spot of such dimensions renders the line structure of the picture less evident to the eye of the viewer.

In the 405-line system, the effective area of the scanning spot on the mosaic is about 0·00008 sq. ins., corresponding to a spot diameter of 0·01 inches, or about 0·25 mm. A unit of that size represents the *effective* elemental area of the iconoscope mosaic.

The Iconoscope—The D.C. Level

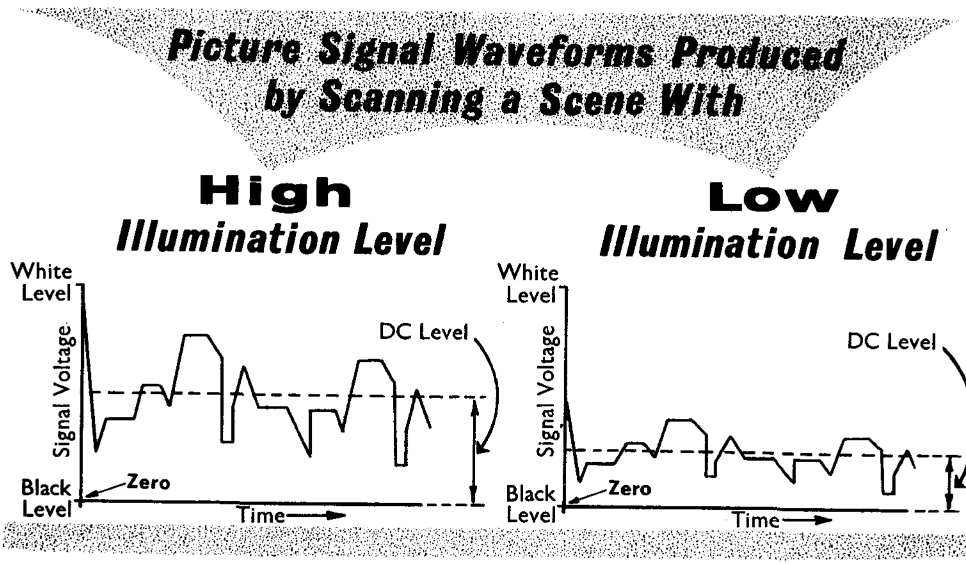
The average value of the picture signals produced by a TV camera tube is called the **d.c. level.** It depends on the average brightness of the scene being televised. For example, the average level of picture signals derived from a scene bathed in brilliant sunshine will be considerably greater than the average level derived from the same scene when it is illuminated by moonlight.

As the illumination of a scene is increased, therefore, so also should be the d.c. level of the picture signals produced by the camera.

In the Iconoscope, however, it is not possible for a direct current to flow between the mosaic and signal plate of the target because the only coupling between these two surfaces is their mutual capacitance, and d.c. cannot flow across a capacitor. Consequently, the mean level of the output signals from the Iconoscope does not follow changes in average illumination. It is therefore necessary to introduce into the output signals before they are transmitted an artificial d.c. level as nearly as possible representative of the mean brightness of the scene.

But you know from *Basic Electronics* that before you can restore a waveform to any given level you need an accurate reference voltage. In all TV cameras, this reference voltage is taken to be the voltage level representing **black,** i.e. the voltage level of the signal when a totally dark area of the scene is scanned by the beam. Unfortunately, as you will read on the next page, there are special difficulties in obtaining a good black-level reference voltage in the Iconoscope.

Meanwhile, note in the illustration below how the d.c. level of the signal alters with the average level of illumination of the scene. In both waveforms, maximum signal amplitude occurs when the beam is scanning the whitest areas of the scene; minimum signal amplitude when it is scanning the blackest areas. Signal amplitudes lying between the white and black levels represent varying shades of grey.



Though the black level of the scene is shown above as zero signal voltage, it is not necessary that black should be represented by that particular level of voltage. Either a positive or a negative level of voltage could be chosen instead.

The Iconoscope—The Black-level Reference Signal

It is a fundamental disadvantage of the Iconoscope that the output signal corresponding to black cannot be held steady. The reason for this is an effect known as *shading*, which you must now understand.

When the beam scans the mosaic of the Iconoscope target, the high velocity of the electrons in it causes a large number of secondary electrons to be struck out of all the silver/caesium globules it touches. Many of these secondary electrons are collected by the final anode and flow to earth, but the majority fall back on to the mosaic—principally, *but unfortunately not only*, on to the photo-cathodes they have just left.

In the top left-hand corner of the mosaic, the secondary electrons have nowhere to fall back save on to the globules they have left. Their return partially cancels the positive charge which their departure caused. As the beam scans further to the right, however, and more particularly as it scans succeeding lines, the secondary electrons it liberates are not only attracted back to the globules they have just left, but also to the still-positive neighbouring globules which have already been scanned.

When the beam nears the right-hand edge of the mosaic and also as it scans the bottom lines, the secondary electrons it liberates behave as before, a number of them wandering off to partially-positive neighbours and so further cancelling their charge. But for the globules on the right-hand and bottom edges of the mosaic, there is no source from which they can attract their share of these wandering electrons—with the result that these areas have a permanent tendency to be *relatively more positive* than the rest of the mosaic.

You already know that the scanning of more positive areas of the mosaic causes larger discharge currents to flow through the signal load resistor, and so for larger voltages to be developed across it. These larger signal amplitudes correspond to the scanning of brighter areas of the scene.

The result is that signals generated by the scanning of the right-hand and bottom edges of the Iconoscope mosaic tend to represent these areas as being brighter than they really are. They show up on the picture screen of the receiver as a kind of whitish flare along its right-hand and bottom edges, and are known as **shading signals.**


The effect of these shading signals is that the level of voltage representing black varies with the position of the scanning spot on the mosaic, being accurate only when the beam is in the top left-hand corner and least accurate when it is in the bottom right. In practice, the best that could be done was to introduce a genuinely black object into every scene, and to obtain an arbitrary black-level reference voltage from that object itself. But it was seldom very satisfactory.

You will now see how the problem was solved in cameras of a later type.

The Image Orthicon

TV cameras of the Iconoscope type which you have just been studying were a great advance on any of the mechanical scanning systems which had preceded them. They were very stable electrically; and, when skilfully used in good lighting conditions, they were capable of producing pictures of reasonably good quality.

But they had their disadvantages also. Although their sensitivity was far in advance of any mechanical scanning system, it was still not as great as could be desired, and studio scenes still needed pretty strong lighting before they could register well on the viewer's screen. Power consumption was therefore high, and the discomfort of the actors considerable.

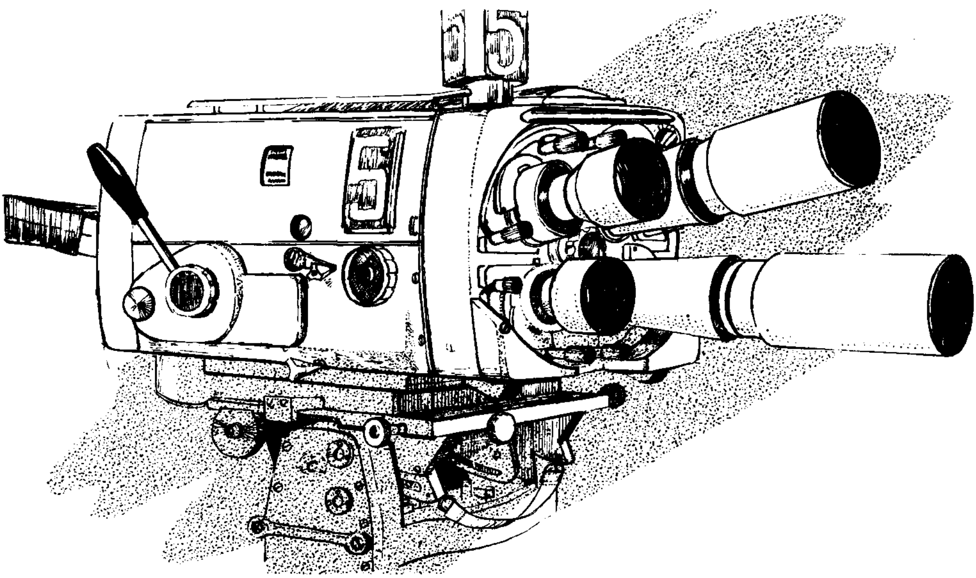
Iconoscope-type cameras had other inherent disadvantages as well. They tended to be large, heavy and of awkward shape. They needed fairly complex correction circuits to counteract the effects of shading signals. And they lacked, as you have seen, the major virtue of having a reliable black-reference level.

Of the range of cameras which have been designed to overcome the defects of the Iconoscope, two in particular are of importance—the **Image Orthicon** and the **Vidicon.**

The Image Orthicon has been by far the most widely used successor of the Iconoscope. Its tube has a sensitivity more than a thousand times greater than has the tube of its predecessor (some Image Orthicon tubes are even more sensitive than the human eye!). It is suitable for work under almost any lighting conditions, and it is extensively used in TV systems all over the world. It is therefore important that you should understand the principles on which it works, and the limitations to which it is subject, before you go on to learn about the Vidicon, which represents the latest development in present-day design.

Here then, to begin with, is a sketch of what a typical TV camera of the Image Orthicon type looks like.

A Typical IMAGE ORTHICON *TV Camera*

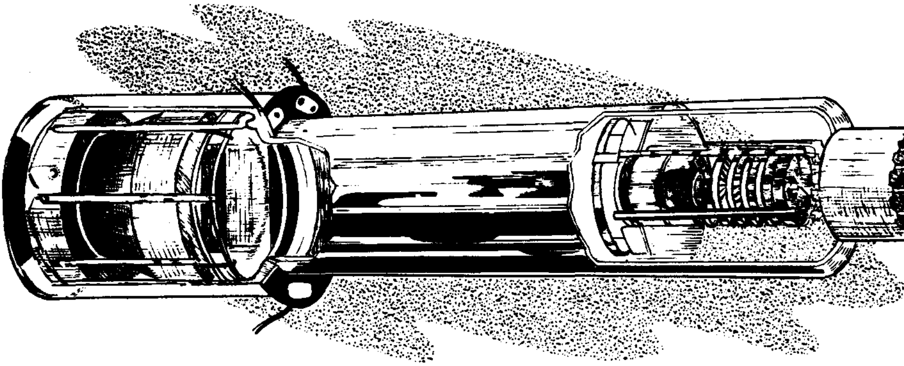


The Image Orthicon—The Camera Tube

The Image Orthicon camera tube is cylindrical in shape. It has at one end an extension of larger diameter which contains a light-sensitive surface. Its physical appearance is represented in the illustration below.

Early types of Image Orthicon tube were 76 mm in diameter; but present-day tubes (as used by the BBC since 1954) are of 115 mm diameter. These 115 mm types are commonly about 480 mm in length.

The IMAGE ORTHICON Camera Tube



The Image Orthicon camera tube works on the following principles.

Light from the scene to be televised is focused on to a transparent photo-cathode at one end of the tube, which emits electrons from points on its inner surface in numbers corresponding to the tonal composition of the scene. These electrons are propelled towards a small and exceedingly thin glass target, on which they produce a positive charge image of the scene by the action of secondary emission.

Because of the extreme thinness of the target glass, the charge-image so produced on its photo-cathode side "leaks through" to its reverse side and is there reproduced unaltered. Glass has a very high resistance in all normal circumstances (*see later, page* 1.54); but the target of the Image Orthicon is so thin that its "through" resistance is very low and it becomes in this direction conductive.

A low-velocity electron beam is then arranged to scan the reverse side of the target, where it neutralizes the charge-image by successively giving up enough of its own electrons to cancel the varying positive charges it encounters. The beam needs to give up more of its electrons to cancel the high positive charges which represent the brighter parts of the scene than it does to cancel the lower charges representing the darker tones.

All electrons *not* given up by the beam as it scans each individual area of charge are reflected back towards the electron gun. More electrons will plainly be reflected back from capacitances corresponding to the darker tones in the scene.

Before these "surplus" electrons return to the gun which originally projected them, however, they are deflected towards an electron-multiplier assembly. This assembly, as you already know, is capable of producing an output signal which is exactly proportional to every variation in the density of the returning electrons.

In this way, the tonal composition of the scene is exactly reproduced in the form of a consecutive stream of rapidly-varying voltage signals.

The Image Orthicon—Construction

The electrode assembly within the Image Orthicon camera tube may be divided into three main sections:

(a) **the Image section.**

(b) **the Scanning section.**

(c) **the Electron Gun/Electron Multiplier section.**

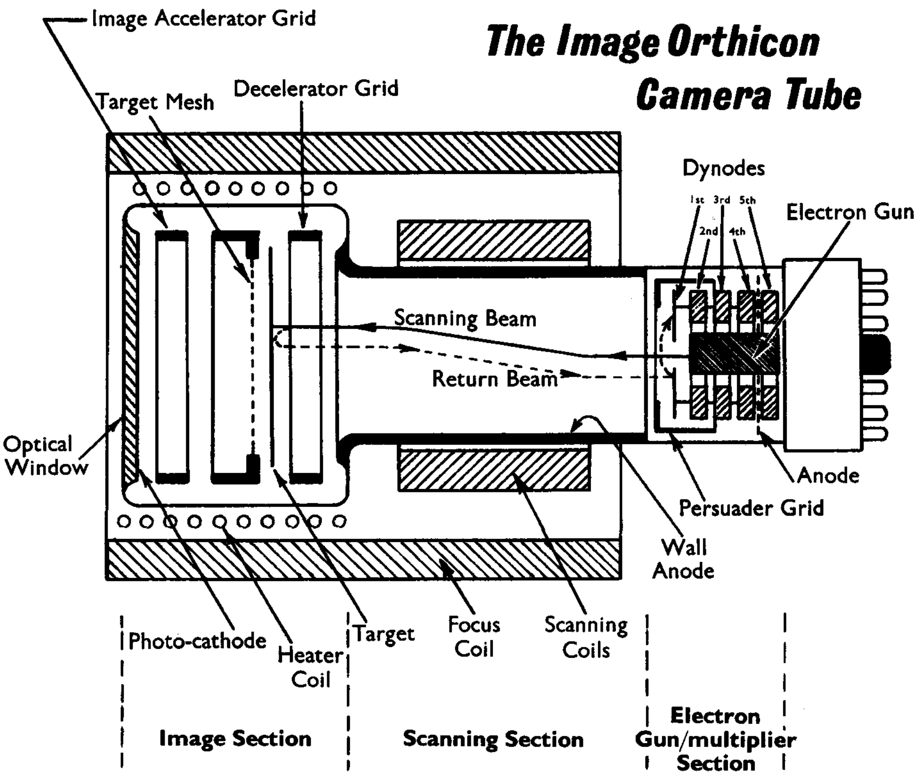
The *Image section* contains the photo-cathode, the target and all the other electrodes used in creating the charge image.

The *Scanning section* contains an accelerating electrode for the electron beam in the form of a graphite coating deposited on the inside wall of the glass envelope, with the horizontal and vertical beam scanning coils mounted outside.

The third section contains a conventional *electron gun* to produce the scanning beam, with a 5-stage *electron multiplier* assembled round the perimeter of the gun.

Around the outside of the tube, covering both image and scanning sections, is placed a *focusing coil* whose function is to produce an axial magnetic field within the tube.

All these components of the tube can be identified in the illustration below, together with one or two others whose purpose you will shortly discover.



The Image Orthicon—The Photo-cathode

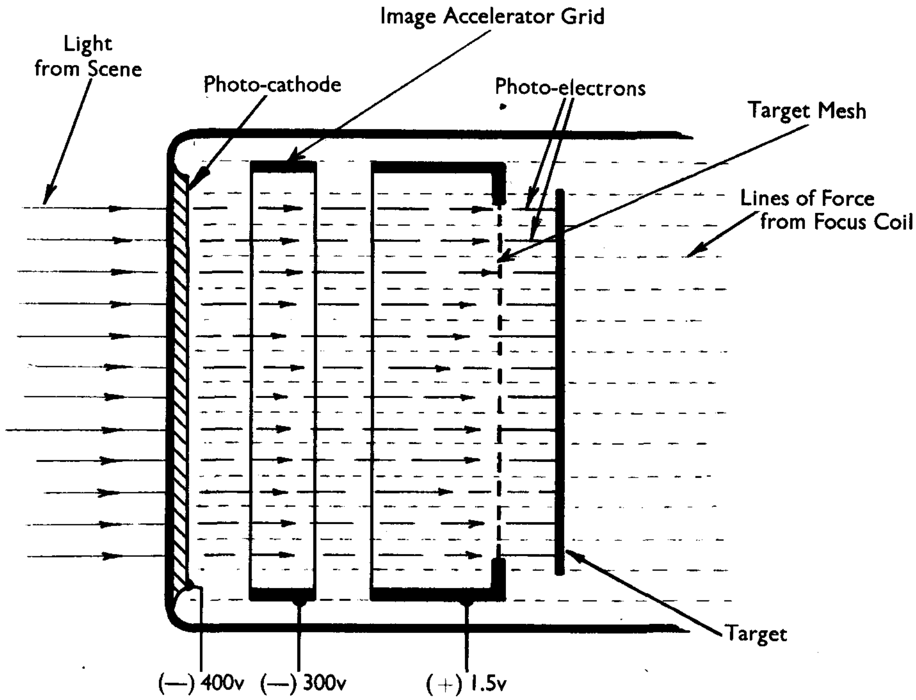
You should now consider the various component parts of the Image Orthicon camera tube in turn, beginning logically with the **photo-cathode.**

Light from the scene is collected by the lens and focused on to the glass end-window of the tube. This has been coated on its inside surface with a special mixture of antimony, silver and caesium which forms a semi-transparent photo-electric surface. This coated end-window is the photo-cathode. It is normally connected to a large negative voltage (typically, minus 400 V).

As you already know, the number of electrons released from the photo-cathode by the impact of light on its surface will vary from point to point according to the tonal composition of the scene—bright areas giving rise to large emission and darker areas to much less.

When they leave the photo-cathode, the electrons are directed towards the target by the potential difference existing between the large negative voltage on the photo-cathode, on the one hand, and (as you will learn on the next page) the less negative voltage on the **image accelerator grid** and the positive voltage on the **target mesh,** on the other.

A direct current is made to flow in the **focus coil,** producing an axial magnetic field which ensures that the electrons travelling towards the target do so in straight paths parallel to the axis of the tube—the photo-electrons being made to follow the lines of force produced by the current in the coil.



The Image Orthicon Camera Tube – IMAGE SECTION

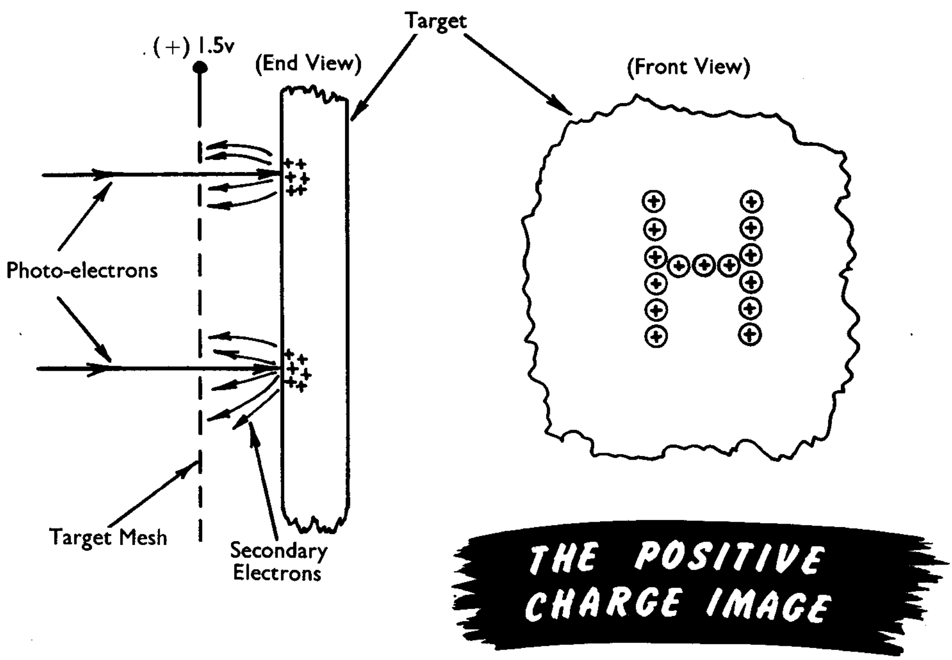
The Image Orthicon—Creation of the Charge Image

When they arrive at the target, the photo-electrons strike it with sufficient force to cause the emission of secondary electrons. Every point on the target from which secondary electrons have been "struck" in this way instantly acquires a positive charge equal in magnitude to the total negative charge removed by the loss of electrons emitted from that point.

The result is that a positive charge-image is formed on the target, every small charge representing an elemental area of the scene. Bright areas of the scene are represented by dense areas of large positive charges on the target, while darker regions are represented by lower concentrations of comparatively weaker positive charges.

But what, meanwhile, has happened to the secondary electrons struck from the target by the varying light signals coming from the lens system and the scene? Left to themselves, they would quickly fall back on to the target from which they came, and in doing so obliterate the positive charge-image on it before it could be put to any use.

To collect these electrons, there is placed in front of the target, but very close to it (about 0·001 inch away), a closely woven mesh of very fine wires to which a small positive voltage is applied. The wires are so fine that they do little to impede the passage of the fast-moving photo-electrons on their way to the target; but the secondary electrons emitted from the target are travelling very much slower, and so are attracted to the mesh and dissipated in the supply circuit connected to it before they can do any harm by falling back on to the target.



The Image Orthicon—The Target

The target in the Image Orthicon consists of a rectangular shaped sheet of glass approximately 50 mm wide and 38 mm high. The glass is extremely thin, typically five thousands of a millimetre, or 0·005 mm—which is thinner than the finest of cigarette papers. The reason for this extreme thinness is, as you know, to keep the effective electrical resistance measured between the surfaces of the target (*i.e.*, through the glass) so low that the positive charges "impressed" by light from the scene on to its photo-cathode side can leak quickly through on to its reverse (scanning) side.

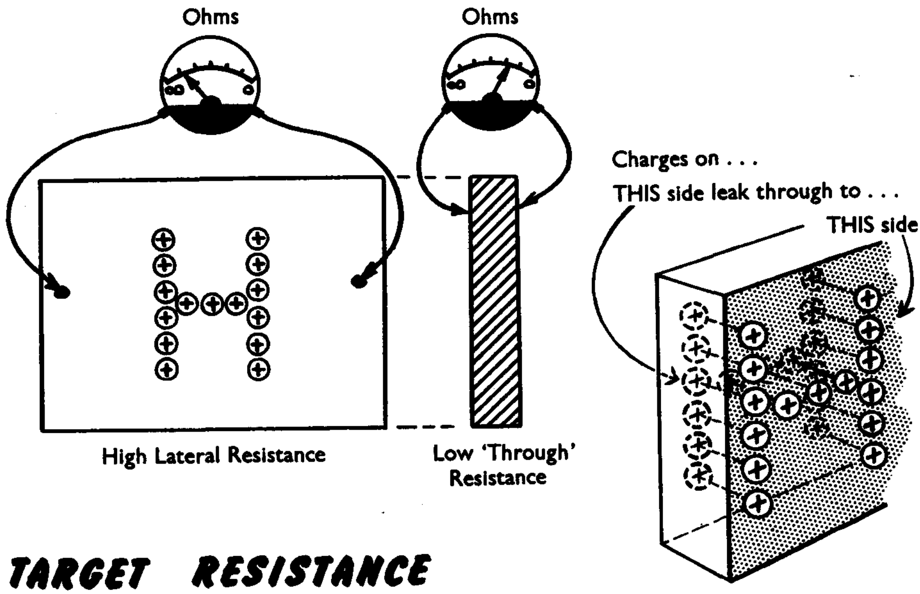
A piece of glass as thin as this needs to be kept small in area lest it vibrate enough to distort the collection and scanning of the charge image. Hence the small size of the Image Orthicon target.

But why, you may ask, use glass at all? Why go to the trouble and expense of making it so exceedingly thin when some other less resistive material could be used which would leak the positive charges through from one of its surfaces to the other just as well, and with far less bother?

The reason is that the target must have a *lateral* resistance which is very high indeed, in order to prevent individual charges from spreading into one another and so destroying the whole pattern of the charge image. Glass is a material which possesses this high lateral resistance to the movement of electrons.

Yet, even so, it is necessary to keep the spacing between adjacent picture elements on the target *about 20 times the thickness of the glass target* if smearing of the charge image is to be avoided.

The diagrams below illustrate these points—but you must not forget, in studying them, that it has been necessary to show the thickness of the glass target as far greater, proportionally, than it really is, in order to show how the target works.



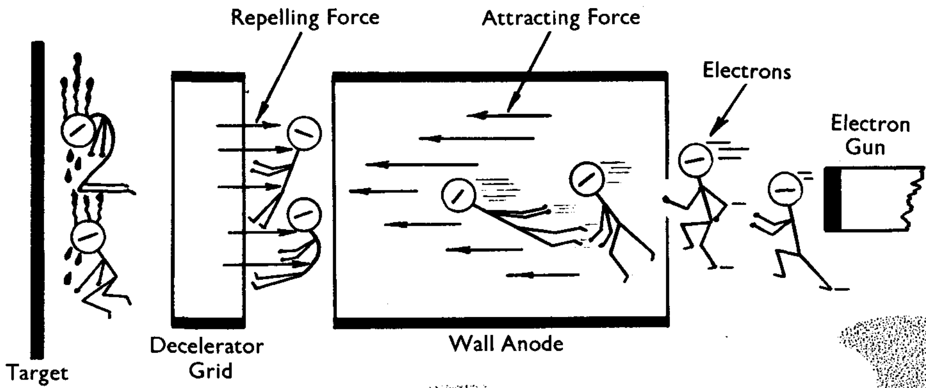
TARGET RESISTANCE

The Image Orthicon—The Scanning Beam

The electron beam used to scan the target of the Image Orthicon is produced in an electron gun similar to that used in the Iconoscope. In the Iconoscope, however, the accelerating voltages of the tube were sufficiently great for the beam to strike the mosaic with considerable force during scanning. This resulted in secondary emission of electrons at the mosaic—which in turn gave rise to the undesirable shading signals.

In the Image Orthicon, the electron beam is first accelerated by the positive potential of the **wall anode** in order to make sure that it is properly directed towards the target. But then, just before it reaches the target, it is deliberately slowed down by the repelling force of the **decelerator grid.**

There is applied to this grid a carefully calculated voltage which is so much *less* positive than the potential of the wall anode that it appears to the approaching electrons to be negative. It slows them down so much that they can only just get through it; and they finally reach the target only because the relatively tiny attractive forces of the positive charge-image stored there pick them up and pull them "home".



When they do reach the target, the electrons act just as they did in the Iconoscope—neutralizing the total positive charge at the point where they hit, and giving up some of their number to do so. The higher the positive charge at any one point on the target, the more electrons have to be given up to cancel it out. There are therefore fewer electrons left over where the beam scans areas of high positive charge caused on the target by the brighter areas of the scene.

Whatever their numbers at any point, the "survivor electrons" are at this instant of time (the cancellation of the charge image) virtually at rest, the attractive and repulsive forces acting on them being momentarily in balance. Almost immediately, however, the still-positive potential of the decelerator grid begins to pull them back towards the electron gun. Very shortly thereafter they come under the still greater attractive force of the much more positive wall anode, which causes an enormous increase in their velocity.

The returning electrons, of course, vary in density along the length of the beam according to the tonal content of the scene.

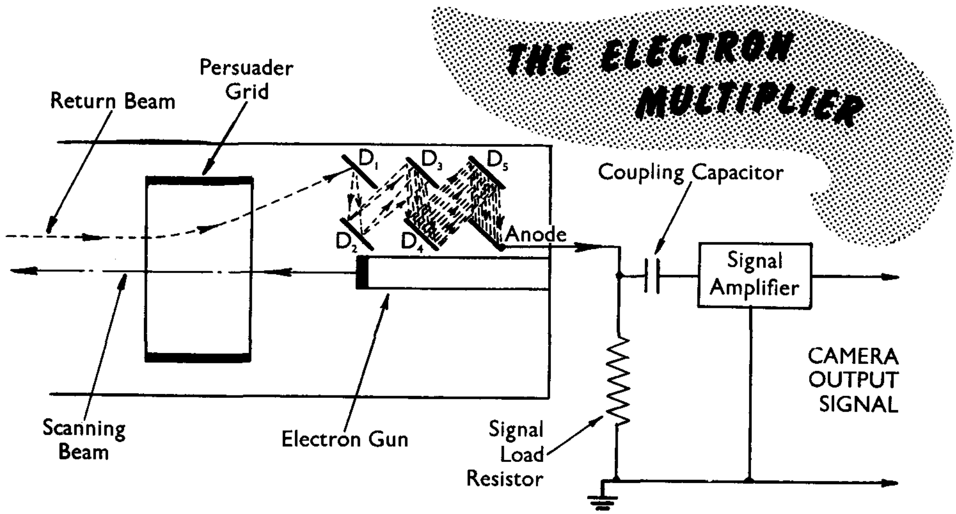
The Image Orthicon—The Electron Multiplier

When they get near the electron gun, the returning electrons are diverted on to the first dynode of the electron multiplier by an electrode aptly named the **persuader grid.** They strike the surface of the dynode, and secondary electrons are emitted—the actual number varying from moment to moment according to the density of the electron beam.

These secondary electrons are attracted by the higher potential of the second dynode, from which additional secondaries are struck—the multiplication process continuing for a further three stages (making five in all), after which the now-much-more-numerous electrons are collected by the anode of the electron multiplier assembly. The signal appearing at this anode is a highly magnified version of the variation in current flow occurring in the electron beam returned from the target.

This signal current is then made to flow through a load resistor connected in series with the anode; and the variations in voltage developed across this resistor by reason of the constantly varying current passing through it constitute the picture signal output of the camera tube.

Despite all the complicated stages through which it has passed, this output signal carries a faithful representation of the tonal composition of the scene.



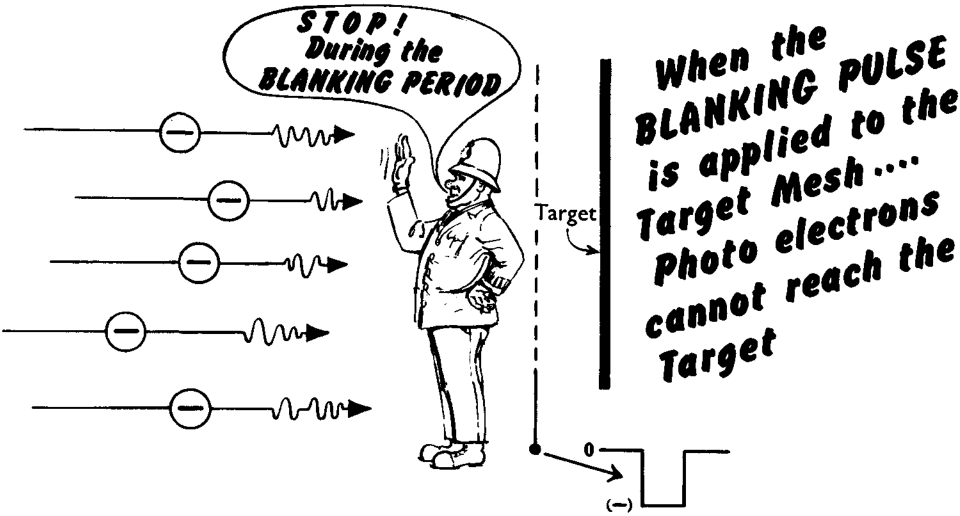
You will see from the illustration that the output signal developed across the anode load resistor of the electron multiplier is connected to the signal amplifier by means of a capacitor. This means that no d.c. can pass from the tube to the amplifier, and that the output signal can at this stage be given no d.c. level (representing, as you know, the mean brightness of the picture).

In the Image Orthicon, however, the target mesh prevents secondary electrons knocked out of the target face by the arriving photo-electrons from falling back on to it during periods of darkness. No charge-image is therefore produced on the target during these periods, and there is in consequence a very accurate black-level reference signal. That being so, the d.c. level can be restored to the output signal at any point in subsequent circuits, using the d.c. restoration technique you learnt about in *Basic Electronic Circuits*, Part 1.

The Image Orthicon—Blanking

The accurate black-level reference signal mentioned on the last page is obtained by simulating the conditions of darkness at the target face for short periods at the end of every line and field scan. This is done by applying a large negative **blanking pulse** to the target mesh at the appropriate moments, so completely repelling for the period of the pulse all photo-electrons travelling towards the target.

The electron beam during these periods of blanking therefore returns with none of its electrons missing, and so can be used to form an accurate black-level reference.



Miscellaneous Points

❶ You have seen that, when there is no charge image on the target, the density of the return beam is constant, and almost equal to that of the scanning beam. There is then no signal output. When a charge image appears on the target, however, the density of the return beam is reduced and an output signal results.

It follows that, since the output signal is derived from a *reduction* in beam current, the output signal must be *negative-going*.

❷ The lateral resistance of the glass in the target is very sensitive to changes in temperature; and unless precautions are taken to minimize such changes, the resolution of the tube will be impaired and smearing of the reproduced image will occur.

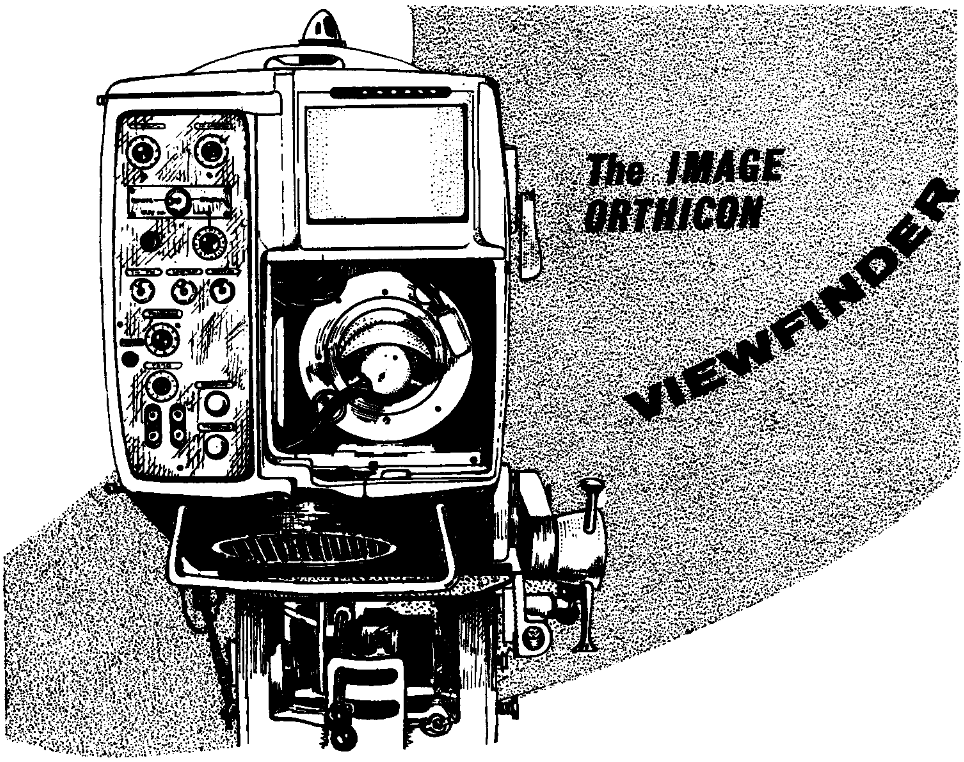
Most image orthicons have their image sections thermostatically controlled by a small heater coil wound round the section. Typical operating temperatures are between 35° and 45° C.

❸ An effect known as *image burn-in*, or *image sticking*, is sometimes experienced on the Image Orthicon target, especially as the tube ages. When the target has been exposed to a stationary scene for a long period (*e.g.*, during the transmission of a test card), an image of the scene can be retained on the target long after the scene has been removed. The effect can generally be cured by exposing the photo-cathode to a uniformly bright scene for a fairly long time.

The Image Orthicon—The Viewfinder

The viewfinder used in the Image Orthicon (and in all modern TV cameras requiring manual operation) is fully electronic, and does not actually look directly at the scene at all. It forms, in fact, a miniature self-contained TV receiver within the camera itself. Part of the output signal from the camera tube is fed to the viewfinder, which displays a reproduced image of the scene on a rectangular CRT generally some 180 mm across.

The advantages of this type of viewfinder are that no separate lenses are needed, and that the brilliance of the image being displayed can be made as bright as desired. This latter facility is of especial value to the operator when a dimly-lit scene is being televised.



The Lens Turret

On the front of all modern TV cameras designed for general-purpose use there is an impressive array of lenses and lens hoods, all mounted on a rotatable turret. This turret can be controlled manually or, in some types, automatically from a remote position.

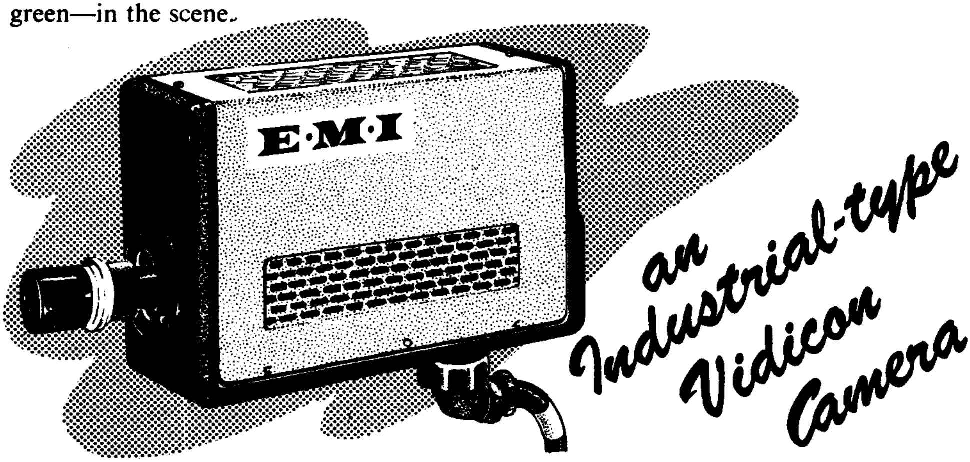
Every lens is designed for a particular function—"close-up", "long-shot" or "zoom". A "zoom" lens (or, to give it its proper name, a **zoomar**) enables a gradual close-up of a distant point to be obtained without interrupting the scene, the camera being made to appear to move towards the scene. This facility is much used in the televising of personal interviews, and in the stage appearances of well-known personalities.

You will see in Section 6 how a zoomar works.

The Vidicon

The Vidicon represents one of the most recent developments in television camera design.

Its camera tube is only about 150 mm long by 25 mm in diameter—which is very much smaller than the tubes used in either the Iconoscope or the Image Orthicon cameras. This small size, combined with its correspondingly light weight, makes the Vidicon very suitable for use in industry (monitoring, for instance, the operation of a process inaccessible to, or dangerous for, human beings) or in field work such as outside "telecasts" by the BBC or ITV, in which ready portability is an advantage. The Vidicon tube is also useful in colour TV—for which cameras need to operate three tubes simultaneously to reproduce the three primary colours—red, blue and green—in the scene.



As against its advantages, however, the Vidicon lacks the extraordinary sensitivity of the Image Orthicon. Early models, too, responded slowly to moving objects in the scene, the reproduction of which on the screen was apt to be marred by "smearing". Great progress has been made towards overcoming this fault; but it remains true that the Vidicon is particularly suitable for the recording of fairly static scenes, in which it is frequently convenient to operate it by remote control.

The **Vidicon Camera Tube** consists essentially of a cylindrical glass envelope containing an electron gun at one end and a light-sensitive surface at the other. There are few internal electrodes, and the complete tube generally weighs less than three ounces.

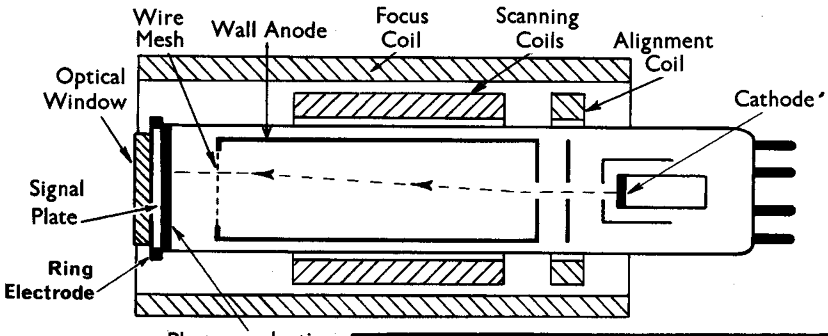
Its essential difference from the Iconoscope and Image Orthicon tubes is that, whereas they employ the principles of photo-electricity and secondary emission respectively, the Vidicon produces a charge image on its target by making use of the **photo-conductive effect.** You will recall that in this effect the *resistance*—and thence the *conductivity*—of a photo-conductive material is affected when light falls on to it. Thus if the target of a camera be coated with a photo-conductive material, areas of high illumination in a scene focused on to this target will be made *more conductive* than areas on which less light falls.

You should now see how this fact can be used to develop the chain of varying voltages which makes up the output signal of the camera tube.

The Vidicon Camera Tube (*continued*)

The envelope of the Vidicon camera tube is closed at one end by a flat, transparent *optical window* made of glass, which is coated on its inside surface with an equally transparent film of conductive material. This film (whose thickness has had to be greatly exaggerated in the illustrations which follow) forms the *signal plate.* It is electrically connected to a ring-type electrode encircling it, and projecting slightly round the outside of the tube.

The inside surface of this signal plate—the surface facing the electron gun—is coated with a thin film of photoconductive material (usually antimony trisulphide) which forms the light-sensitive *target* on which the charge image is to be created. In darkness, both signal plate and target carry a small positive voltage of about 35 V.



The VIDICON Camera TUBE

Situated some 2·5 mm inside the target, and stretched across one end of an open-ended tube known as the *wall anode*, is a fine-wire *target mesh.* Both mesh and anode carry a large positive voltage (200-300 V). One of the functions of the target mesh is to protect the target from bombardment by negative ions produced in the electron gun. These negative ions are electrically-balanced atoms which have captured an extra electron and have so acquired a negative charge. They are heavy, and would cause "burn spots" on the target if they were allowed to hit it. But, being slow moving, they are readily trapped by the high voltage on the mesh and dissipated in the supply.

The target mesh has also another function which will be explained on the next page.

The wall anode itself extends for most of the operational length of the tube. It forms the final electrode of the electron gun, and also provides a uniform accelerating field for the electron beam.

The *scanning coils*, which bring about both horizontal and vertical deflection of the scanning beam, are arranged round the tube approximately midway along the wall anode. A further small coil, known from its function as the *alignment coil,* is also situated round the tube, close to the electron gun itself.

Lastly, right round the whole of the outside of the tube, is a long solenoid known as the *focus coil.* The magnetic field produced by this coil "straightens up" the electron beam just before it reaches the wire mesh, and ensures that it scans the target squarely at right angles—in paths which are all parallel to the axis of the tube.

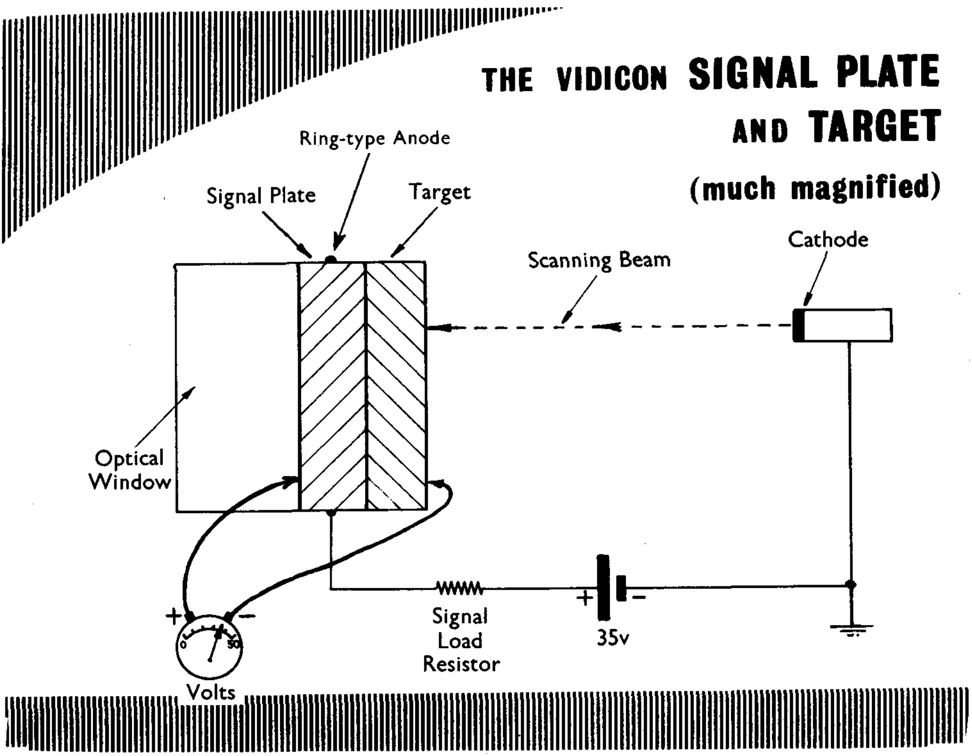
The Vidicon Camera Tube (*continued*)

The second function of the target mesh is very important. Still with no light from the scene falling on to the target, the electron beam is set to scan it. Accelerated by the (+) charges on the wall anode and the mesh, the electrons in the beam are moving fast when they reach the mesh. But when they pass through it, they suddenly find themselves facing a *much less positive* charge of only 35 V on the target. They are so much slowed down in consequence that they are able to do no more than just cancel the (−) charge on the target and bring it down to zero.

Since the mesh covers the whole of the target area, it is thus able to provide for the beam a *uniform decelerating field* between mesh and target, whatever part of the target the beam may be scanning.

The situation in the tube is now this. The cathode of the electron gun, the electron beam and the target are at earth, with the beam forming a conducting path between them but with its velocity greatly reduced just before it reaches the target. The signal plate is at 35 V. With no light falling on it, the coating of photo-conductive material between signal-plate and target has a resistance so high that it can be regarded as an insulator.

A strong electric field therefore exists between the 35 V on the signal plate and the earthed target, because the two are so close together. If anything were to happen to lower the insulation of the dielectric between them, current would at once flow from the target to the plate.



The target is now exposed to light from the scene—and the insulation of the dielectric is at once affected. You will see what happens on the next page.

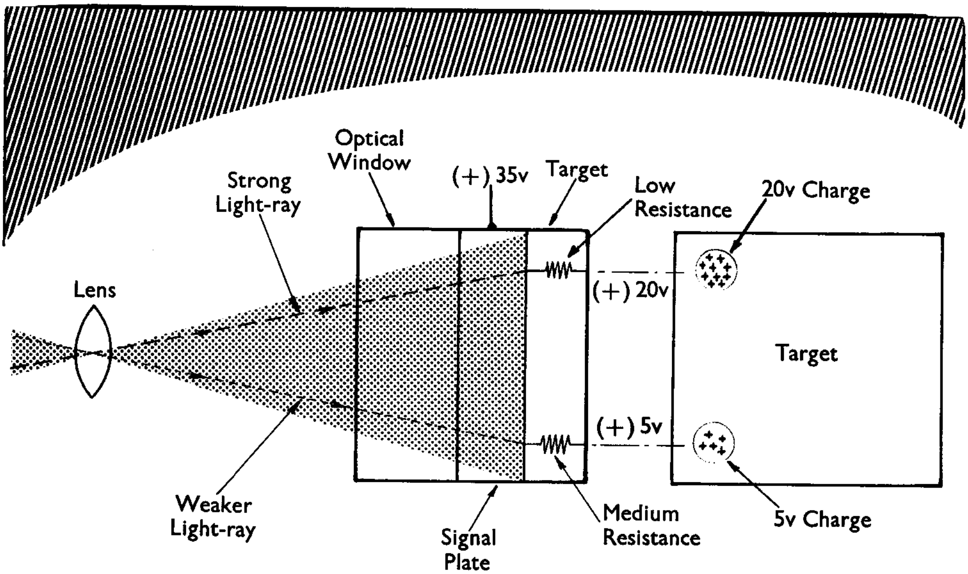
The Vidicon Camera Tube (*continued*)

When light from the scene to be televised is focused on the optical window of the tube, it passes through the transparent signal plate and falls on to the side of the target *closest to the scene*. The effect of this light is to lower the resistance of the photo-conductive coating on the signal-plate side of the target by amounts corresponding to the tonal composition of the scene—bright areas bringing about large changes in resistance, and darker regions having little effect.

At every point on the target where the resistance has been lowered, a current flows from the earthed side of the target to the signal plate. These currents build up slowly, and are not in themselves of operational significance. They do, however, take electrons away from the earthed (scanning) side of the target, and in doing so cause the potentials on it to rise above earth—the amount of each such rise depending on the decrease of the resistance through the target at that point.

In this way, a pattern of positive charges is formed on the scanning side of the target, the more positive areas of which correspond to the brighter areas of the scene being televised.

These tiny charges—each of which forms a picture element—are prevented from spreading into one another by the very high lateral resistance of the antimony tri-sulphide (or other material forming the target film).



How the **CHARGE IMAGE** *is formed*

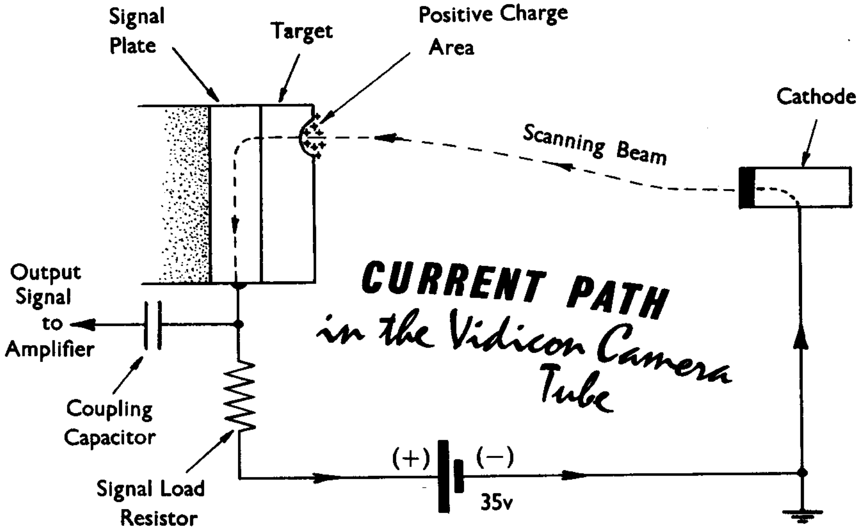
The charge image appearing on the target is then scanned by the low-velocity electron beam in the usual way; and electrons from the beam neutralize the positive charges they touch. Wherever this happens, the varying positive potentials of the charge image are brought sharply back to earth.

Electrons not needed for neutralization are returned towards the cathode (electron gun), and play no part in the action; for in the Vidicon tube no use is made of the return beam.

The Vidicon Camera Tube (*continued*)

When electrons from the beam encounter the large, dense areas of charge on the scanning side of the target—those which represent the high-lights of the scene being televised—more of the electrons will be required for neutralization than will be the case elsewhere. Whatever their numbers, however, these neutralizing electrons flow in a swift current through the target, into the signal plate, through the ring-type electrode surrounding it and thence through the signal load resistor.

The further end of the signal load resistor from the signal plate is connected to earth, through the low impedance of the 35 V supply. The complete current path is therefore as follows: cathode—scanning beam—areas of positive charge on the target—through the now-conductive parts of the target—signal plate—signal load resistor—35 V supply—cathode.



One of the drawbacks of the Vidicon tube is its slowness in responding to sudden changes in illumination. This is due, partly to the time it takes to neutralize the charge image on the target, more importantly to the time which the target needs to return to its fully-insulating state after the light which has reduced its resistivity has been removed.

This phenomenon is known as **photoconductive lag.** Its value is typically "18% after one scanning period, for peak-white decay". This means that, $\frac{1}{25}$th of a second after peak-white illumination has been removed from the target, picture signal output is still 18% of full amplitude. The effect, which will obviously be more pronounced at low levels of illumination, manifests itself in a tendency for rapidly-moving objects to become "smeared".

The scanned area of the Vidicon target, and therefore the size of the charge image stored on it, is very small indeed—typically only some 13 mm by 9 mm. The diameter of the scanning spot is, as you know, about 0·25 mm. This means that it is difficult to avoid scanning overlap—with consequent impairment of **resolution.** Some Vidicon tubes can only take about 200 scanning lines without overlap; and a 405-line scan sometimes gives an overlap of as much as three lines.

The Picture Signal

Whatever the type of camera tube used—Iconoscope, Image Orthicon or Vidicon—the *overall shape* of the output signal is identical. Since it does not matter which type of tube is taken as an example, therefore, let us look at the type of output signal which the Iconoscope produces.

Look at the illustration of that rather pretty girl on the page opposite, and suppose that her face is the scene being televised. (Save when she is being photographed in the closest of "close-ups", of course, there will almost always be more in the scene than just bits of the girl's hair and face; but the principle will not be affected even if an over-simplified example be chosen to illustrate it.)

Suppose, then, that this face is focused on to the Iconoscope target, and that a charge image of it is created on the mosaic. Suppose further (though this is, of course, impossible in practice) that this charge image is visible to the naked eye, and that it in fact appears on the mosaic exactly as does the girl's face in the illustration. Suppose, lastly, that the electron beam of the tube is scanning the even numbered lines across the mosaic, and that it has just reached the beginning of Line 200 at the moment shown. Consider the shape of output signal which this one scan of the beam, and the two or three scans immediately following it, will produce across the signal load resistor of the TV camera.

As the beam moves from left to right across Line 200, it begins in a white area (represented by highly-charged regions of the charge image) and then moves into the very dark area of the girl's hair. The output signal consequently falls sharply from the comparatively high level which represents white to a much lower level only a little higher than that representing black. Then, leaving the girl's hair, the beam moves across her cheek, which appears in a black-and-white picture as varying shades of grey. The output signal therefore takes up a level lying between black and white, and remains there until the beam reaches the girl's nose. Note the two sharp dips in the output signal representing her nostrils.

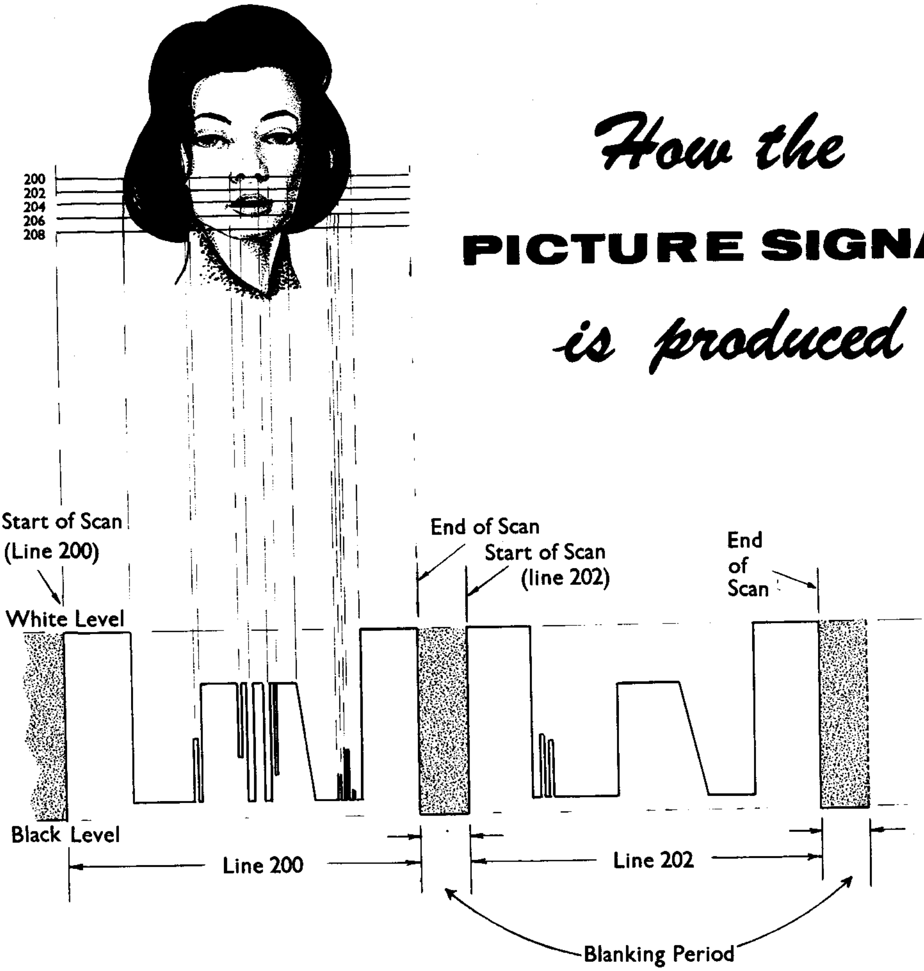
The signal continues to vary in this way until the beam reaches the end of Line 200. It is then suppressed by the blanking pulse and returned to the left-hand side of the mosaic. The next line in the scanning sequence is No. 202, which traverses the rather "uneventful" region of the girl's face between her nose and her mouth. Line 204, however, has the job of scanning her lips—and it is perhaps not surprising that the corresponding output signal (you will find it in the signal train at the foot of the illustration) begins to jump about a good deal more excitedly than did its immediate predecessor!

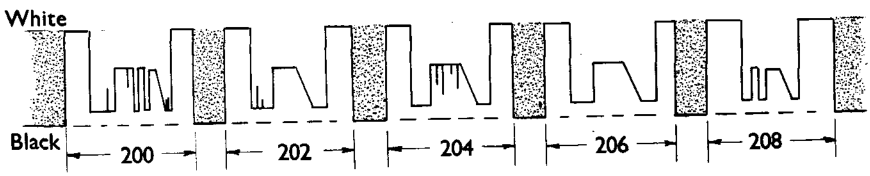
The most important point to note about the whole process is that, whereas the scanning lines across the mosaic lie one underneath the other in space, the output signals corresponding to them occur *one after the other in time.* Every signal in the resulting train occurs at a definite time after the end of its predecessor—and thereafter at a definite time after the beginning of the first line of the scanning field.

This train of output signals is called the **picture signal.** It is taken, through an amplifying stage, to a control unit in the studio where (as you will see) special pulses are added to it to form the **video signal.**

Remember that the polarity of the picture signal, which is positive-going in the Iconoscope scan pictured above and in the Vidicon, is negative-going in the Image Orthicon.

How the PICTURE SIGNAL *is produced*





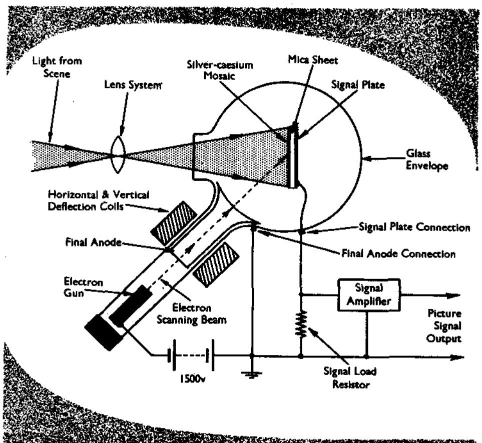
REVIEW of the TV Camera

All TV cameras operate by converting the tonal composition of a scene into equivalent charge images on a photo-sensitive target; and then reading these images off with an electron beam to form a train of electrical impulses whose amplitudes are proportional to variations in the brightness of those areas of the scene to which the impulses correspond. This train of electrical impulses is called the *picture signal.*

The first effective TV camera to use the scanning process was the *Iconoscope*. It was in use for many years, and pictures of good quality could be obtained with it.

But its inadequate sensitivity made it satisfactory only in strongly-lit studios or on sun-lit outdoor locations. Also, the presence of shading signals (caused by secondary electrons struck out of the mosaic by the scanning beam) not only called for special correction circuits and for expert operators to keep adjusting them during transmission, but also made it impossible to achieve a reliable black-level reference signal.

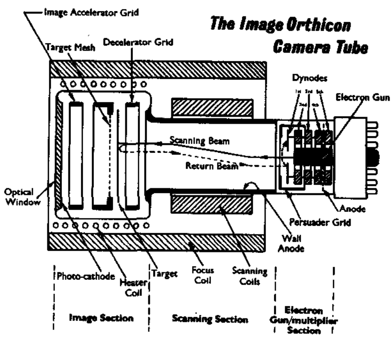
For these reasons, the Iconoscope camera is now obsolescent, and the most commonly-used modern TV cameras are the *Image Orthicon* and the *Vidicon*.



THE ICONOSCOPE – *Standard Emitron Type*

The *Image Orthicon* makes use of the photo-electric and secondary-emission effects to create the charge image on its target. Light from the scene is converted into a stream of photo-electrons whose density increases with the brightness of the scene. The stream impacts on the target and knocks electrons from its surface, to be caught by the target mesh. Positive charges of varying size are created where these electrons have been knocked away, and leak through to the other side of the very thin target.

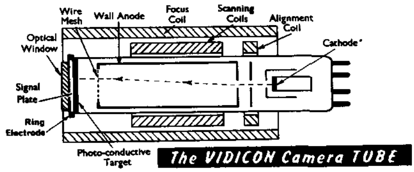
The Image Orthicon Camera Tube



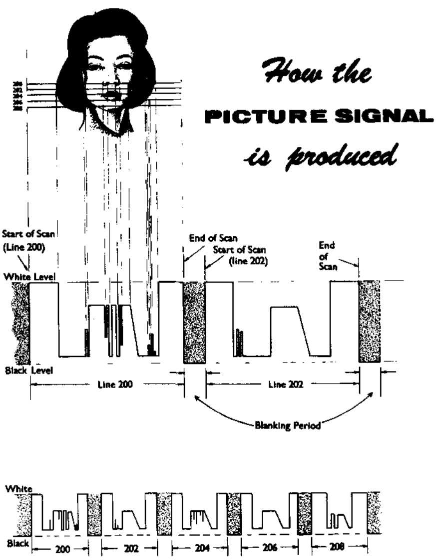
There they are scanned by a low-velocity electron beam, which gives up enough electrons to neutralize every charge it encounters. The "survivor" electrons (now fewest where the light was strongest) are returned towards the electron gun and directed into an electron multiplier assembly, the amplified output from which constitutes the picture signal.

REVIEW of the TV Camera (*continued*)

The *Vidicon* is the smallest of all TV camera tubes, and is much used in closed-circuit systems and in colour television. Its charge image is created when the light from the scene is used to lower the electrical resistance through the target. Small currents, of no operational significance, flow from the earthed (scanning) side of the target to the positive signal plate, leaving positive charges of varying size behind them. When these charges are neutralized by the electrons in the scanning beam, the discharge currents flow through the target, signal plate and signal load resistor to form the picture-signal output of the tube.



The VIDICON Camera TUBE



The overall shape of the picture signal is the same, whatever the type of camera used to produce it; but the polarity of the signal varies. Whereas the Image Orthicon camera produces an output which is negative-going (*i.e.*, the whiter areas of the scene are represented by more negative excursions of the output signal waveform), the Vidicon picture signal is positive-going—as is that of the Iconoscope pictured opposite. In the case illustrated, the lighter areas of the girl's face are represented by a (+) jump in the output signal waveform; the darker areas of her hair and nostrils by a signal not far above the black-level reference voltage of the picture.

The important feature of all scanning systems is that, whereas the scanning lines across the target lie one underneath the other in space, the output signals derived from them occur one after the other in time.

Another camera tube even more recently developed than the Vidicon is the *Plumbicon*. Although fully capable of producing a good black-and-white picture signal from a televised scene, this new tube seems likely to find its principal uses in colour TV. Since it is hardly, if at all, used in any operational British television system at the moment of writing, its characteristics have not been covered in this Series.

§ 5: THE VIDEO SIGNAL

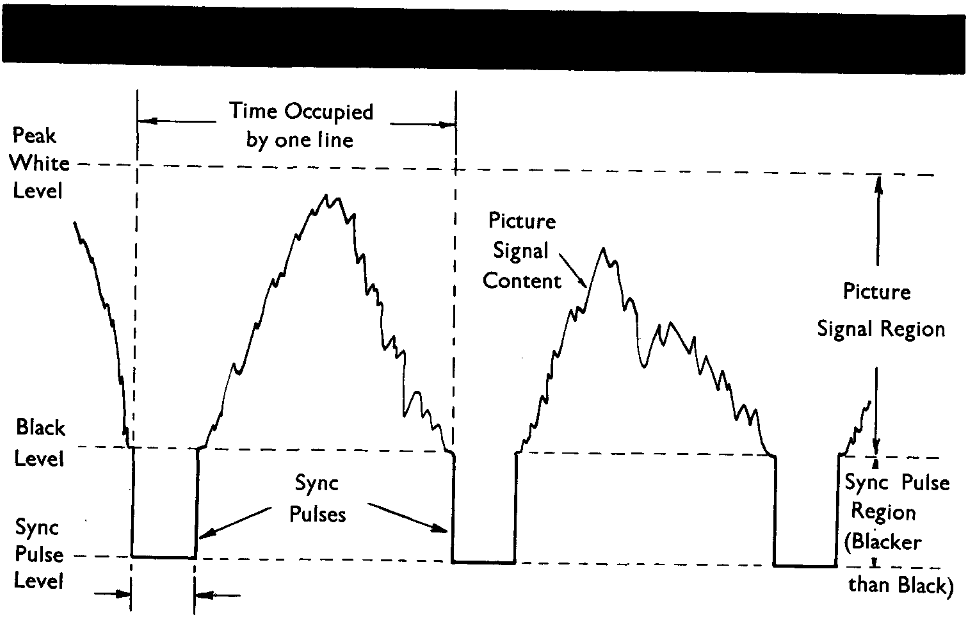
If the image seen by the viewer is to be a faithful reproduction of that sent out by the studio, it is essential that the scanning spot shall move across the picture tube in the receiver at the same speed and at the same time as the scanning spot moving across the target of the camera tube, and that it shall at all times occupy the same relative position in its scanning field. If any of these conditions are not realized, it will be impossible to keep the picture steady at the receiver; and it may either drift across the screen, dissolve into multiple images, or even break up altogether.

To ensure accurate synchronization between transmitter and receiver, therefore, a series of synchronizing pulses are mixed with the picture signal in the studio, and are transmitted with it. At the receiver (as you will learn in detail in Part 2), these pulses are separated from the picture content of the received signal, and are used to synchronize the line and field timebase generator circuits feeding the picture tube.

The **sync pulses** (as they are commonly called) take the form of rectangular-shaped pulses of voltage, of very accurately defined duration, introduced into the signal during the blanking periods which are needed at the end of every line scan and every field scan to allow the scanning beam to fly back to the beginning of the next line or field without being visibly traced out on the screen.

The pulses are formed when signal amplitude is first reduced to blanking level, and then driven into the "blacker-than-black" region beyond the black-level reference voltage for the brief period of time needed for pulse formation.

The composite signal containing *the picture signal plus its associated sync pulses* is known as the **video signal.** The illustration below shows a section of a typical video signal, consisting of two complete line scans and the three sync pulses associated with them.



THE VIDEO SIGNAL — 405 line system

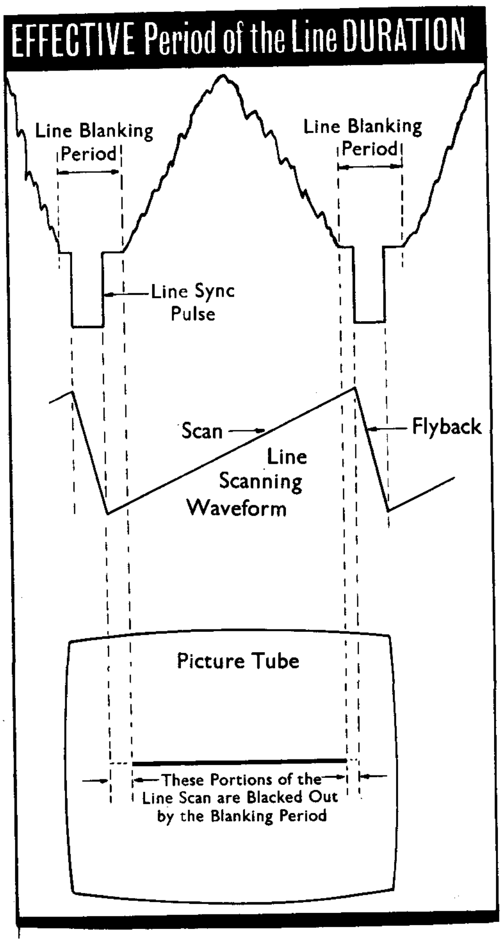
The Line Sync Pulse

In all television systems, it takes many hundreds of lines to make up one complete field. A great many more line sync pulses than field sync pulses are therefore required. Since it is obviously essential that the comparatively rare field sync pulse shall be easily picked out and recognized by the circuit, its effective width is always made considerably greater than that of the line sync pulse—even though the amplitude of the two types of pulse is kept the same.

Consider now the **line sync pulses** in more detail.

As the scanning beams in the camera and picture tubes complete the scanning of every line, they are suddenly made to return to the left-hand sides of the target and screen respectively, so as to be back in the correct positions for beginning the scans of the next line. This sudden reversal of the scanning beams is (as you know) called the **flyback** or **retrace**; and the time taken for its completion is called the **flyback** (or **retrace) time.**

To prevent the charge on the target from being destroyed during flyback of the camera tube beam, and to stop the flyback being visibly traced out on the picture tube screen, the two scanning beams are individually suppressed during the flyback periods by a negative **blanking waveform** applied to the two tubes. It is during the period of this blanking waveform that the synchronizing pulses are added to the picture signal.



Flyback at the end of every line is initiated by the arrival of the line sync pulse. The time interval between any two successive line sync pulses therefore represents the full duration of a scanning line (including flyback).

For reasons which you will see on the next page, the overall duration of the line blanking period is made about twice as long as the duration of the line sync pulse. This means that the *effective* period of the line duration (*i.e.*, the period during which the picture signal is actually visible on the screen) is determined not by the time interval separating the line sync pulses themselves, but by the time interval separating the line blanking periods.

The point is brought out in the illustration to the left, in which the spaces between the two pairs of dotted lines to the left and right of the picture tube are blacked out by the blanking period. In practice, of course, these two "blacked-out" spaces do not appear on the screen of the picture tube at all, for the length of the scan is always arranged to fill the whole width of the screen. The "blacked-out" areas exist, none the less, even if they are not seen.

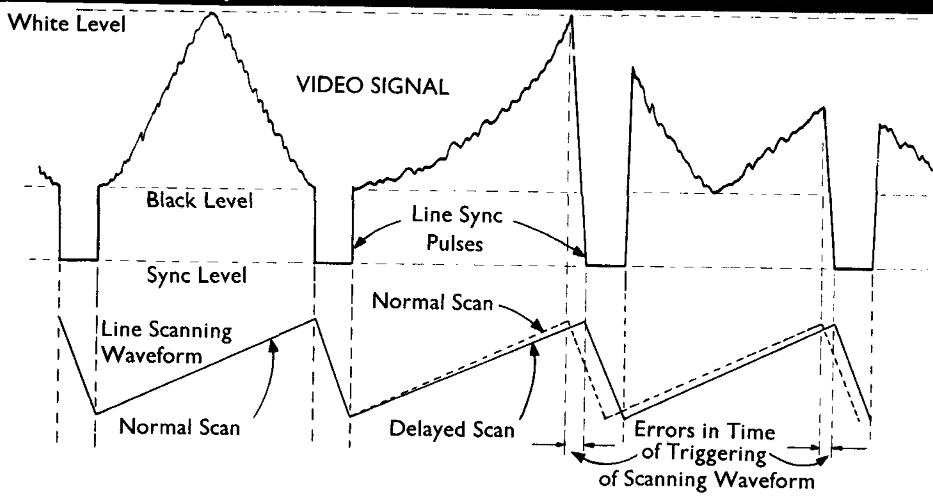
The Line Sync Pulse (*continued*)

The general shape of the video signal waveform during the presence of the line sync pulse is the same in all TV systems, the only difference lying in the relative values of the time intervals between different parts of the waveform.

There are two reasons why the duration of the line blanking period is approximately twice that of the line sync pulse. The first is that sufficient time must be allowed for the picture-signal content of the video waveform to fall to blanking level before the start of the line sync pulse. If this decay time were not allowed for, the shape of the leading edge of the sync pulse would be affected by the magnitude of the picture signal, and the precise time at which the timebase generator circuit was triggered would be ill defined. In other words, the time required for the sync pulse to reach full amplitude would depend on whether it happened to start from peak white, from black, or from some intermediate value. The result would be erratic triggering of the line timebase generator circuit, and consequent distortion of the reproduced image.

In practice, the line sync pulse is introduced a few microseconds after the commencement of the line blanking period, this brief delay period being known as the **front porch.** You can see it in the illustration on the page opposite; but the reason why it is needed appears in the picture below, which shows what would happen if the front porch were not there.

Why the FRONT PORCH is needed

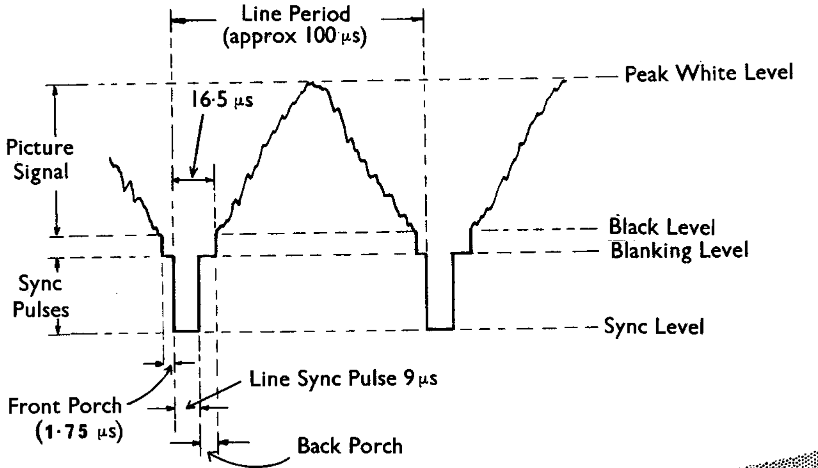


The second reason for the long blanking period is to allow time for flyback of the camera and picture tube scanning beams at the end of every line to be properly completed. This is done by maintaining the picture signal at blanking level for a few microseconds after the end of every line sync pulse. This delay period is known as the **back porch.** The new scan starts from varying points along this back porch, as soon as flyback from the previous scan is complete.

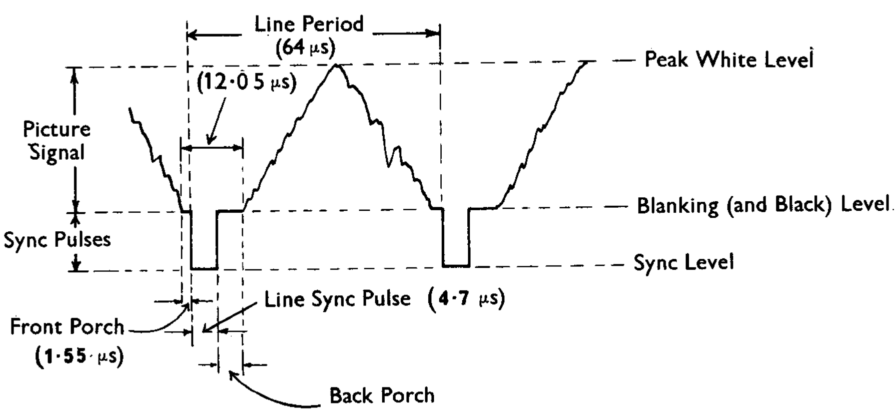
The general structure of the video signal during the period of a single line scan is shown, for both the 405-line and for the British 625-line systems, in the illustration occupying the whole of the page opposite.

GENERAL STRUCTURE of the VIDEO SIGNAL DURING A SINGLE LINE SCAN

THE 405-LINE SYSTEM



THE BRITISH 625-LINE SYSTEM



The Field Sync Pulse

When the scanning beams in the camera and picture tubes finish the scanning of a complete field (that is to say, when they have—in the 405-line system—scanned 202½ lines), they are made to return very quickly indeed to the top of the target and screen so as to regain the correct positions for beginning the scan of the next field.

This re-positioning of the beam at the end of every field is very similar to the operation of line flyback, except that the beam (as you will shortly see) does not travel in a straight line, and takes much longer to return to the top of the screen or target than it does to return to the start of a new line. The time taken to complete the re-positioning is called the **field flyback** (or **field retrace**) **time.**

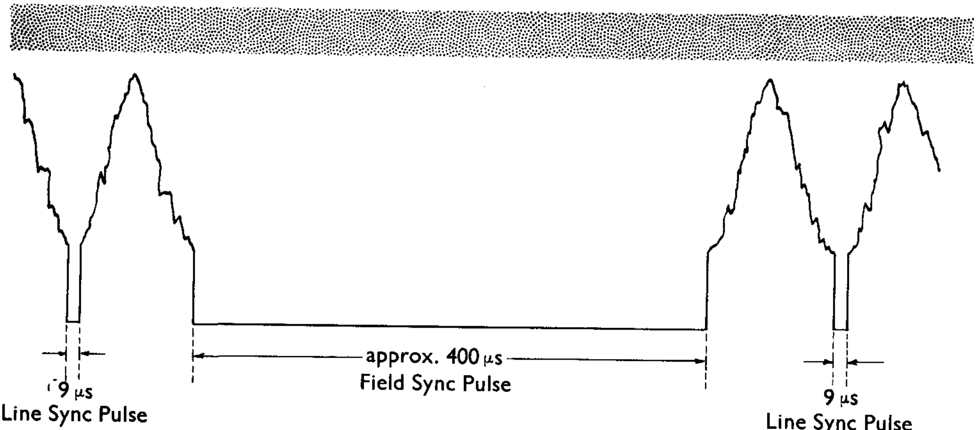
For the same reasons as in line flyback, the scanning beams of the camera and picture tubes are both suppressed during the period of field flyback by the application of a **field blanking waveform** applied to the two tubes. It is during the period of this field blanking waveform that the field sync pulse is applied.

Exactly as with the line sync pulses, field flyback is initiated by the arrival of the field sync pulse. The time interval between any two successive field sync pulses therefore represents the full duration of a complete field. In both 405-line and the British 625-line systems, this interval is *one-fiftieth of a second.*

You already know how important it is that the arrival of the field sync pulse shall be readily distinguished by the timebase generator circuits in the receiver from the many hundreds of line sync pulses which have gone before and which come after it. This recognition is ensured by making the duration of the field sync pulse *more than forty times as long* as the duration of the line sync pulse. Simple integration circuits preceding the timebase generator circuits can easily distinguish such differences in pulse duration, and can therefore recognize the field sync pulse as soon as it arrives.

The separation of the line and field sync pulses from one another, and from the picture signal content of the video signal, is performed by what are called **sync separation circuits** in the TV receiver. These circuits then route the sync pulses to the appropriate timebase generator circuits. You will be learning about them in Part 2.

The essential difference in the duration of line and field sync pulses is shown in the illustration below.



RELATIVE DURATION of line & field sync pulses

The Field Sync Pulse (*continued*)

You will naturally have supposed, from what you have read so far, that the field sync pulse is a single pulse of a few hundred microseconds' duration. In fact this is not so, and you must now see why.

In neither of the British TV systems is the duration of a complete line scan more than 100 microseconds. During the presence of a field sync pulse of several hundred μs duration, therefore, several of these line scans would be lost. The effective duration of the field sync pulse in the 405-line system, for instance, is about 400 microseconds, or the equivalent of four line-scan periods, each 100 μs long. During this period the line timebase generator circuit would (unless something were done about it) be without synchronizing pulses at all, and would probably slip out of synchronism.

This would not be serious in itself, for the scanning beam is blacked out during the period of the field sync pulse anyway. But when the field sync pulse is removed and the line sync pulses take over again, the line timebase would often take a few lines to recover its original synchronism; and this would mean erratic triggering during the first few lines of every field, with consequent distortion of the picture on the screen.

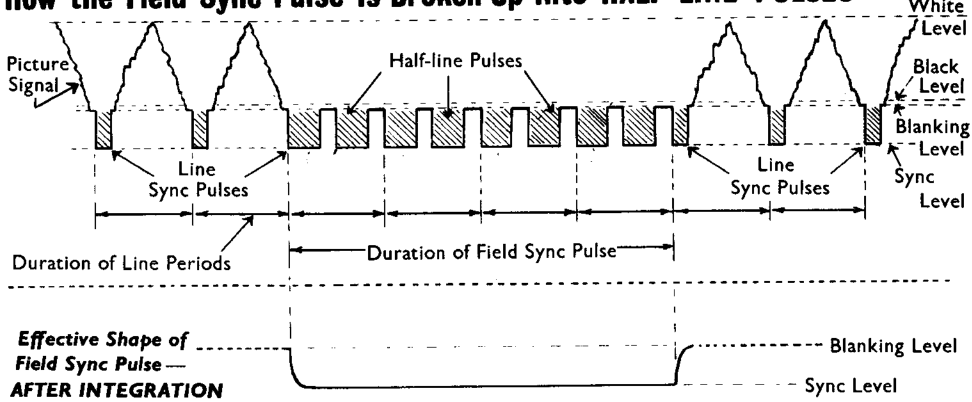
Steps must therefore be taken to ensure that line synchronization is not lost during the period of the field sync pulse. This is achieved by building up the field pulse itself out of a series of shorter pulses, recurring at *twice line frequency*, and each of somewhat longer duration than the normal line sync pulse. The shorter pulses are called **half-line pulses.** Their function is as follows.

You will remember that, in order to effect proper interlacing, the field flyback has to start half-way along the last line scan of every second field. One sync pulse must therefore be available at *the end of a line* for starting the odd-line fields, and another sync pulse *half-way along a line* for starting the even-line fields.

In the field sync pulse as a whole, every alternate half-line pulse triggers the start of an odd-line field, and the remaining alternate half-line pulses trigger the start of the even-line fields. The moment of onset of every second half-line pulse coincides with the moment at which the normal line sync pulse would have fired had it not been suppressed during the field blanking period.

This somewhat complicated arrangement is illustrated in the diagram below.

How the Field Sync Pulse is Broken Up into HALF-LINE PULSES



The Field Sync Pulse (*continued*)

While the half-line pulses are doing their job of maintaining *line* synchronization during the period of the field sync pulse, an identical train of them is being applied to a simple integration circuit quite separate from the synchronizing circuit of the line timebase. The job of this integration circuit is to produce out of the train of half-line pulses a single wide pulse of equivalent length, which will serve for purposes of *field* synchronization.

Field Flyback Path

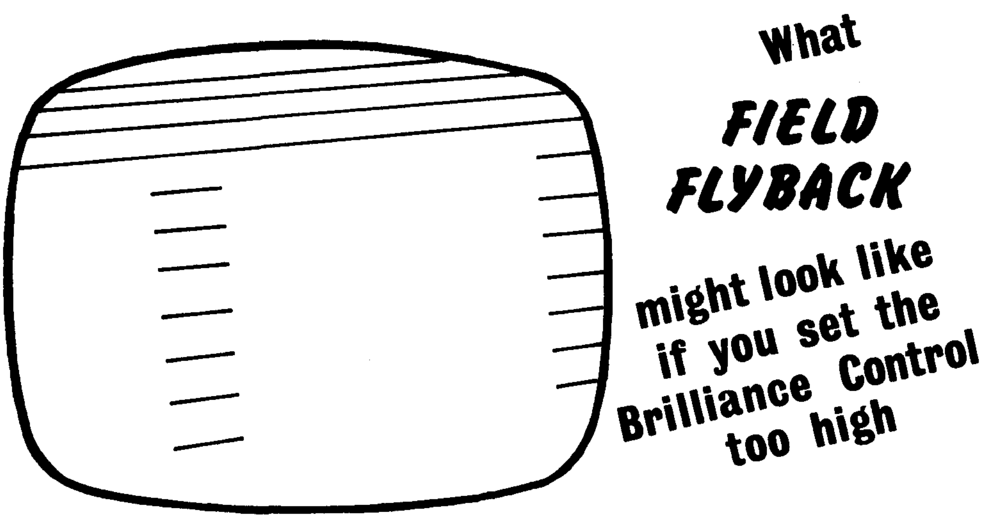
You may have been surprised to read, two pages back, that the distance which the scanning beam travelled during the period of field flyback was considerably greater than the distance travelled by the beam during the period of line flyback. The reason for this is that the scanning beam, on completion of a field, does not return to the top of the screen (or target) by a direct route (as was shown in the simplified diagrams in Section 3), but rather does so in a series of zig-zag lines.

This is because the line timebase generator continues to work, and to be synchronized, during the full period of the field sync pulse, including its flyback time. The scanning beam is therefore deflected across the screen a number of times as it progresses towards the top of the screen.

The path traced out by the beam during its return to the top of the screen is normally prevented from appearing on the picture tube by the field blanking waveform applied to the grid of the tube.

It is, on some receivers, possible for you actually to see the path traced out by the scanning beam during field flyback simply by increasing the setting of the *Brilliance* control on your TV receiver. This has the effect of altering the point at which the beam of the picture tube is cut off—this point is normally adjusted to coincide with the black level of the video signal—until the flyback becomes visible.

What you will actually see when you do this will vary from receiver to receiver, but it generally takes the form shown in the illustration below.



The Field Sync Pulse *(continued)*

The short lines seen in the illustration on the last page are produced during the short blanking-level periods between the broad pulses of the field sync pulse; the longer lines during the longer periods between the narrow pulses of the **post-sync field blanking period,** which will be explained shortly.

The lines will appear to be sloping at an angle much greater than that of the normal scanning lines, particularly towards the bottom of the screen. This is because the beam is being returned to the top of the screen at a rate much faster than that of its normal downward motion during the scanning period of the field. The variation in angle of slope of the flyback scans is caused by the non-linear shape of the deflection current produced in the timebase generator during flyback.

Composition of the Field Sync Pulses

The composition of the field sync pulses in the British 405- and 625-line systems are basically similar; but certain additions are made at the beginning and end of the 625-line pulse which you should know about. The field sync pulses of the two systems must therefore be described separately.

The Field Sync Pulse in the 405-line System

In this system the field sync pulse has an effective duration of four line periods (as you will see if you look at the illustration over the next page). It is made up of a cluster of *eight half-line pulses*, each of about 40 μs duration, separated by seven return-to-blanking-level intervals each of 10 μs duration. The full duration of the pulse is thus $(8\times40)+(7\times10) = 390$ μs, which is virtually the equivalent of the four line periods mentioned above.

The repetition rate of the 40 μs half-line pulses is (as you would expect from what you learnt two pages back) made twice that of the line sync pulses, so as to ensure synchronization of the line timebase circuit during alternate fields.

The end of the field sync pulse is followed by a return to blanking level for a period approximately equal to the duration of ten lines, *i.e.*, a total duration of 1,000 μs. This period is needed so as to allow adequate time for completion of the field flyback. It is known as the **post-sync field blanking period.**

It is, of course, just as important that synchronization of the line timebase circuit should be maintained during the post-sync field blanking period as it was during the period of the field sync pulse itself. Now, however, there are no complications of interlacing to worry about, for field flyback has already started by the time the post-sync field blanking period begins. The post-sync blanking period is therefore interrupted by line sync pulses at the normal repetition rate.

You will have gathered from the above that the overall duration of the *field blanking period* is equal to about **1,400 μs**—a field sync pulse of about 400 μs, plus a post-sync field blanking period of about 1,000 μs. This is the equivalent of 14 line periods, and is a point of real practical importance.

It means that, **in every field of 202½ lines, 14 lines are totally suppressed during the field blanking period.** And since there are two fields in each complete picture, **a total of 28 lines is lost in every picture.**

The *effective* number of lines in the 405-line system (that is to say, the number of lines which are available for presenting the actual picture information) is therefore not 405, but (405−28 =) **377** instead. As you will see in the next Section, this fact has an important bearing on the size of the bandwidth required for transmission of the vision signal.

The Field Sync Pulse in the 405-line System (*continued*)

The illustration opposite shows the detailed composition of the field blanking period in the 405-line system, for both the odd- and even-line field scans. For convenience and clarity of presentation, the lines are numbered in the order in which they are actually produced, *i.e.*, 1 to $202\frac{1}{2}$ in the even-line field, and $202\frac{1}{2}$ to 405 in the odd-line field—although, as you well know, the even-line field really produces lines 2, 4, 6, 8, 10, etc., in the picture, and the odd-line field lines 1, 3, 5, 7, 9, etc.

Note especially in the illustration that the field sync pulse occurs **at the end of a line** on completion of the even-line field; but **half-way along a line** on completion of the odd-line field.

The Picture-Sync Ratio

Although it rather interrupts the sense, the rest of this page must be used for a brief discussion of *sync pulse amplitude.* Read it in conjunction with the illustration on page 1.107.

The relationship of picture signal amplitude to sync pulse amplitude is termed the **picture-sync ratio.** The value of this ratio at the transmitter depends on the answer to the question: What is the highest picture-sync ratio which will give adequate synchronization under conditions of low signal strength at the receiver? Obviously, a very high picture-sync ratio in the transmitted signal will give a waveform with good picture-signal content, but it will be useless if synchronization cannot be maintained; while a very low picture-sync ratio could give good synchronization but a picture signal so inadequate as to be no good to the viewer.

In practice, the ratio chosen is generally the one which makes synchronization *just* possible when the picture signal is of *just* acceptable quality.

The relative magnitudes of the picture signal and sync pulse contents of the video signal are usually expressed as *percentages of the peak amplitude of the modulated r.f. carrier radiated from the transmitter.*

In the 405-line system, the sync pulses are always *negative-going*, and their maximum excursion is represented by almost zero carrier amplitude (0-3%). Blanking level is represented by 30% modulation of the carrier. Black level is determined by the contrast range of the camera tube, and usually lies between 37% and 39% modulation. (The gap between blanking level and black level is often called the *pedestal.*)

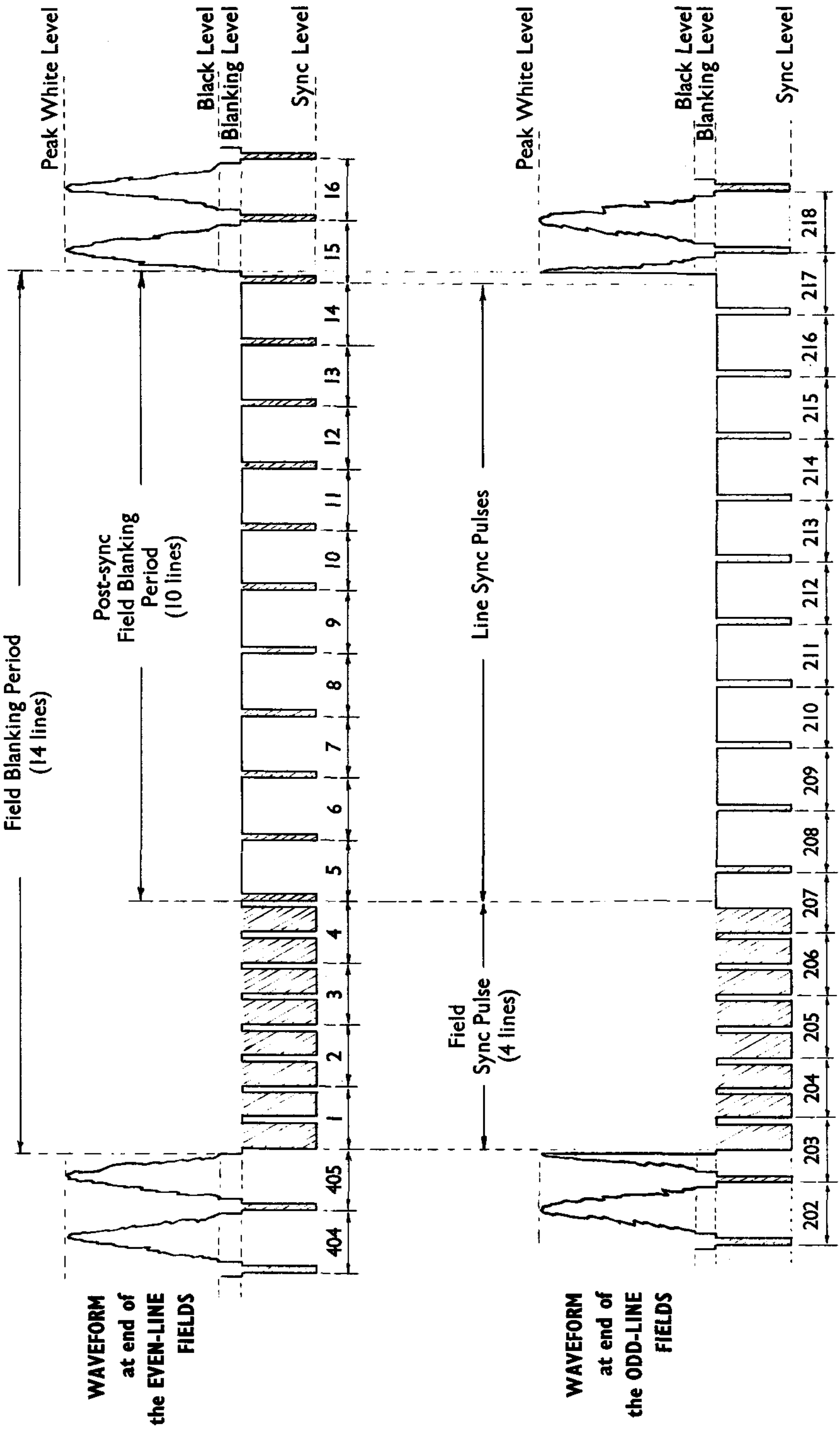
Thus the final picture-sync ratio in the 405-line system is very nearly 2 : 1—the amplitude of the sync pulse being from about 3% modulation to about 38%, and the amplitude of the picture signal from black level to peak white at 100% modulation.

In the British 625-line system, the picture-sync ratio is almost the same as in the 405-line system, but the modulation values of the carrier differ. The sync pulses are always *positive-going*; and an increase in picture signal amplitude brings about a decrease in carrier amplitude.

The maximum excursion of the positive-going sync pulses is represented by 100% modulation of the carrier. Blanking level (which is also black level) is represented by 75% to 77% modulation. The sync pulses therefore occupy some 24% of the maximum carrier amplitude during modulation.

The picture-signal content of the vision signal ranges from a black-level modulation of about 76% down to a peak-white level of 18-20% modulation. Carrier amplitude is never reduced to near zero, as it is in the 405-line system.

FIELD BLANKING PERIOD — THE 405-LINE System



The Field Sync Pulse in the British 625-Line System

You learnt three pages back that certain additions are made at the beginning and end of the field sync pulse in the British 625-line system which are not present in the 405-line pulse. These additions are known as **equalizing pulses.** Their purpose is as follows.

Perfect interlacing can only be achieved in any system when the scan of the last line of alternate fields is terminated exactly at its half-way point, and when the first line of the following field is started at the corresponding half-way point. The scanning lines of the odd- and even-line scans then fall evenly between one another, and the interlacing is correct.

To achieve this, the field flyback for alternate fields must be initiated at precisely the half-way point of the last line, and the flyback periods for both fields must be identical. If flyback is started too soon or too late, or if its duration differs between the two fields, the spacing between lines of the fields will be uneven and the interlacing poor. This will make the line structure of the picture presented at the receiver more obvious, particularly on picture tubes of the larger sizes; and the effect will be more noticeable still if the moment at which flyback is initiated is liable to drift.

In the even-line field of the 405-line system, flyback is started at the end of the last line, so that the time interval between the last line sync pulse and the start of the following field sync pulse is the duration of one line, or about 100 μs. At the end of the odd-line field, however, the flyback is started half-way along the last line, so that the same time interval is only about 50 μs. Similar differences exist at the end of the field sync pulse and the start of the line sync pulses in the post-sync field blanking period; and interlacing is thereby impaired.

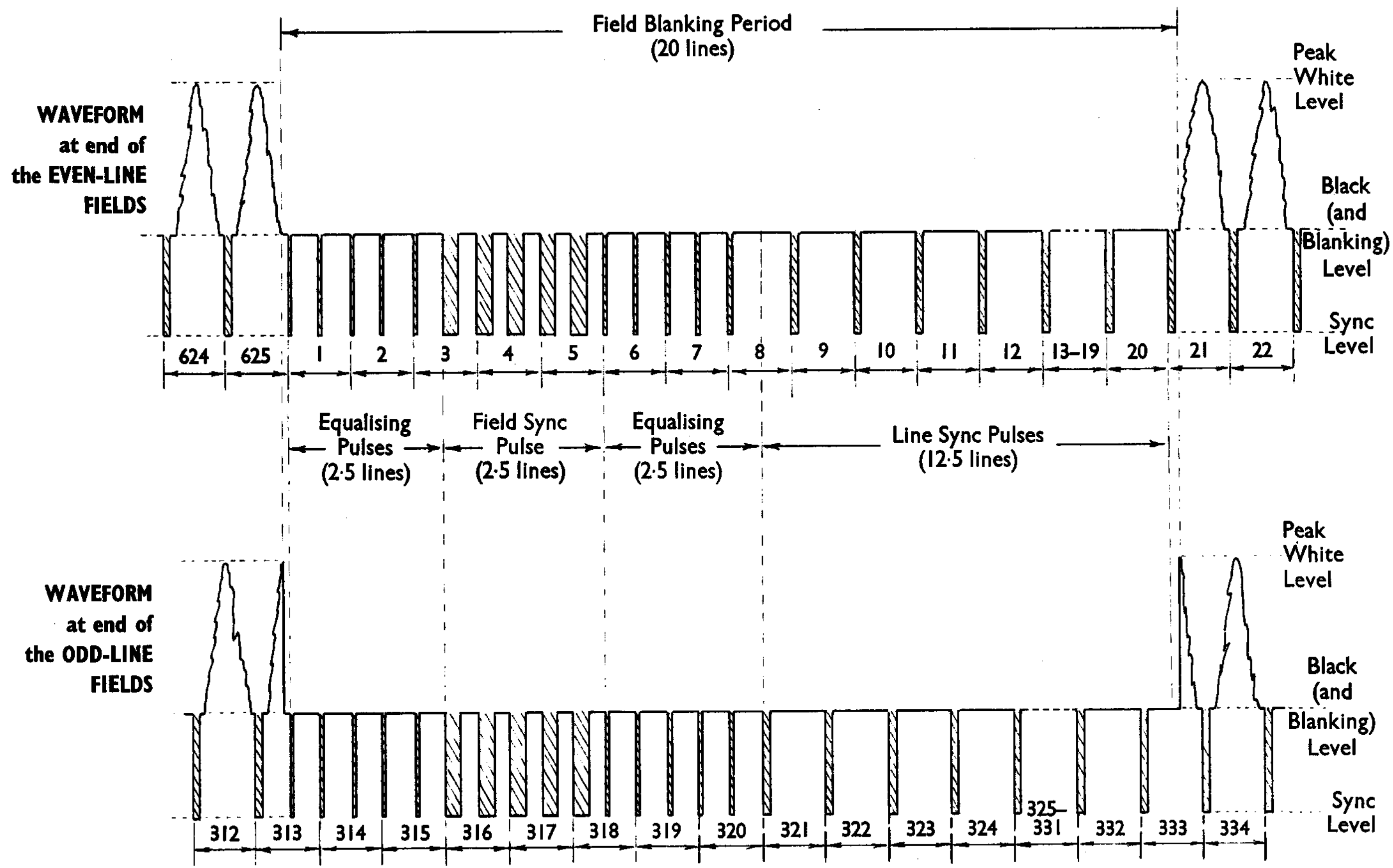
This defect of the 405-line system is obviated in all 625-line systems by the inclusion of a train of narrow "get-ready" pulses at the start and finish of every field sync pulse. These *equalizing pulses* have half the width of normal line sync pulses, and a repetition rate of twice line frequency, *i.e.*, the same frequency as the half-line pulses which comprise the field sync pulse itself. You will learn how they do their job when you get on to the so-called *separation circuits* in the receiver, in Part 2.

Apart from the equalizing pulses, the composition of the field blanking period in the British 625-line system differs little from that in the 405-line system. It is shown in detail in the diagram on the opposite page.

The field sync pulse itself consists of a cluster of five half-line pulses, each of about 27·5 μs, separated by four return-to-blanking-level periods, each of 4·7 μs. Effective duration of the sync pulse is therefore nearly 160 μs, equivalent to **2½ line periods.** Repetition rate of the half-line pulses is twice that of the line sync pulses, as in the 405-line system, and for the same reason.

The sync pulse is preceded by a group of five equalizing pulses having a total duration equal to 2½ line periods. The pulses occur at twice line frequency, and each has a duration of half that of a line sync pulse (2·3 μs). A similar cluster of five equalizing pulses *follows* the field sync pulse; and is succeeded in turn by a further blanking-level period of 800 μs, interrupted by line sync pulses at line frequency. Overall duration of the field blanking period is thus about 1,300 μs, equal to the period of 20 lines.

In the British 625-line system, therefore, 20 lines are lost in every field, making 40 in every picture. The effective number of scanning lines is thereby reduced from 625 to 585.



FIELD BLANKING PERIOD

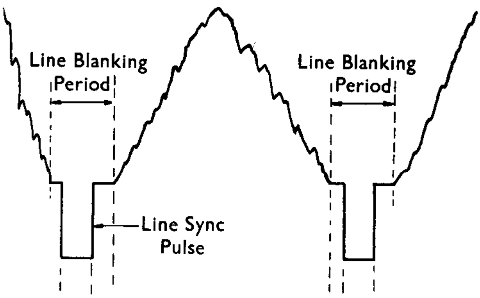
The BRITISH 625-LINE System

REVIEW of the Video Signal

The purpose of sync pulses is to ensure that the movement of the scanning beam in the picture tube is kept in perfect synchronism with the movement of the scanning beam in the camera tube, and that both beams are held at all times in the same relative position on their respective tubes. If this is achieved, the electrical impulses representing the transmitted scene will be delivered to the picture tube of the receiver in exactly the same order, and at exactly the same speed, as they were created in the first place.

Two kinds of sync pulse exist—one for synchronizing the scanning lines, and the other for synchronizing the camera-tube/picture-tube fields. Both are rectangular pulses of voltage which extend into the blacker-than-black region of the video signal.

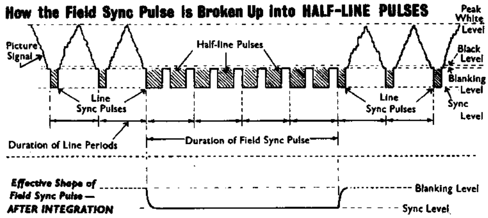
***Line Sync Pulses* are single, narrow pulses added to the picture signal during the line blanking periods. They are used to initiate line flyback, and recur at the same frequency as the scanning lines. The duration of a line sync pulse is about 10% of the line scanning period in the 405-line system, and about $7\frac{1}{2}$% of the corresponding period in the British 625-line system.**



***Field Sync Pulses* consist of broader (half-line) pulses which are added to the picture signal during the field blanking period. When passed through an integrating circuit, these pulses produce a single broad pulse which is used to initiate field flyback.**

The effective duration of the field sync pulse is deliberately made much greater than that of a line sync pulse so as to make it easily identifiable by the sync pulse separation circuits in the receiver.

How the Field Sync Pulse is Broken Up into HALF-LINE PULSES



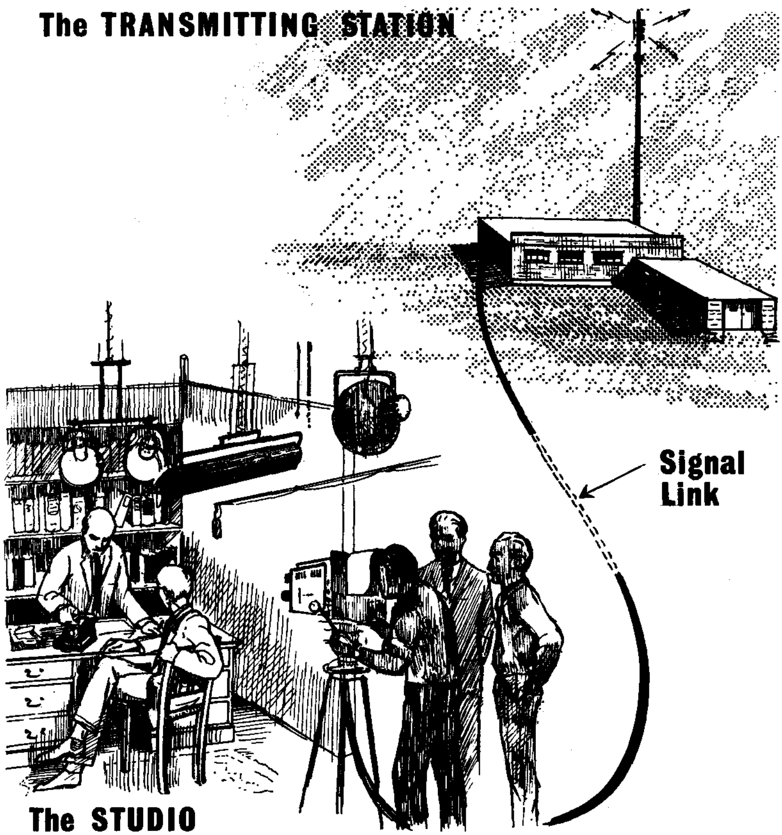
***Equalizing Pulses* are used in all 625-line systems to ensure that interlacing is not impaired by differences in the time at which the field sync pulse arrives at the starting-points of alternate fields. They take the form of groups of very narrow pulses, recurring at twice line-repetition frequency, inserted in the field blanking period immediately before and after the field sync pulse itself.**

***All Sync Pulses* are applied to the picture signal when it is passed through a piece of apparatus known as the Camera Control Unit situated in the television studios. You will see how this unit works in the next Section.**

The output of the control unit is the *video signal* complete.

§ 6: THE TELEVISION STUDIO

It may come as a surprise to you to know that the **televison studio** and the **television transmitter** are two entirely separate entities, often situated many miles apart. For example, the BBC's studios at their big Television Centre near the White City in London are about 10 miles away from the nearest transmitter at the Crystal Palace, and over 400 miles from the Kirk-o'Shotts transmitter in Scotland.



Yet both these transmitters, and all the other BBC transmitters in the United Kingdom as well, are for a large percentage of their broadcasting time supplied with signals originating in the London studios.

There are also, of course, a great many smaller studios and outside broadcast units situated throughout the country, but even the programmes from these are routed through a central control point before being relayed to the national Transmitter Network.

The object of this procedure is to enable programmes originating from different sources to be accurately mixed and phased with one another before being transmitted. A good example of the need for this accurate mixing is a sports-news programme, which will often include on-the-spot items derived from outside broadcast units and from studios situated all over the country. You would be irritated indeed, if, every time the scene changed, your receiver suffered a momentary loss of synchronization!

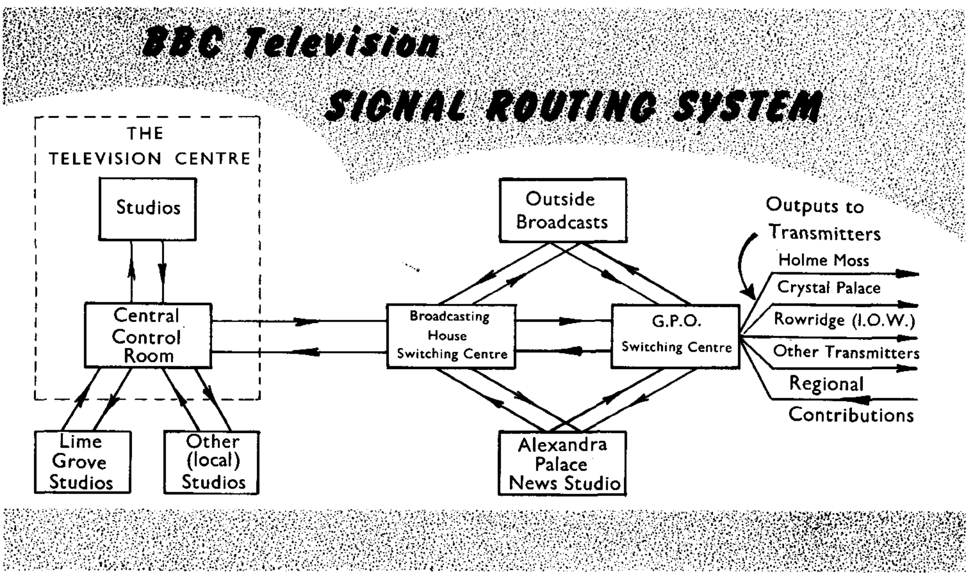
Signal Routing

It will help you to get an overall picture of the complex business of producing and distributing a television programme if you follow out the routing of the various signals which go to make up an imaginary *Sports Round-Up* televised by the BBC on a Saturday evening from Television Centre in London.

The sports reporter who is compering the programme will be sitting in one of the many studios in the Centre, surrounded by a number of display boards and so on, enabling him to show (let us say) positions of the leading teams in the First Division of the Football League as a result of the day's matches. All the sound and vision signals emanating from this studio will be fed to a **Central Control Room** within the Centre, where they will be "married up" with the appropriate signals coming in from Regional studios, outside broadcast units, etc., carrying the sound and vision record of scenes from sports centres such as Aintree racecourse, the links at St. Andrews, or the football grounds of Sunderland, Aston Villa or Twickenham.

From the Central Control Room, the signals representing the completed programme will be fed by cable to a **Switching Centre** situated in Broadcasting House some four miles away in Central London. From here the signals are relayed, also by cable, to a second Switching Centre in London which is owned and operated by the **General Post Office.** This GPO Switching Centre is responsible for routing the signals over GPO land-lines or by SHF microwave links to the several transmitting stations of the BBC National Network which are scheduled to broadcast the sports programme. (This GPO Switching Centre, by the way, provides an identical service for the transmitters of the ITA.)

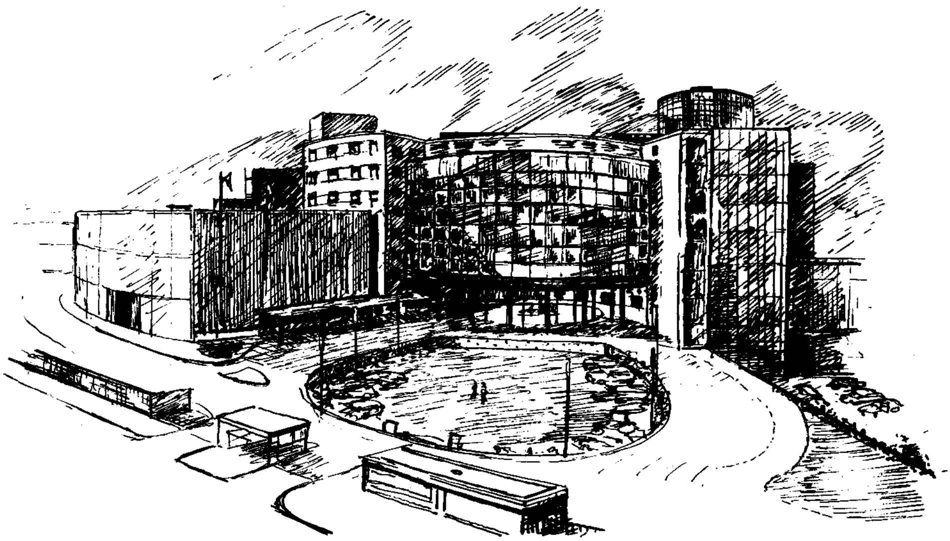
The diagram below shows how all these various points are inter-connected, the arrows indicating signal direction. You will see that the Switching Centre in Broadcasting House itself receives signals from outside sources; but these signals are all sent to Television Centre for technical assessment before being returned to the Switching Centre for subsequent transmission.



The TV Studio

The layout and operating procedure of television studios varies in different countries throughout the world. Much depends on the scale of the programmes habitually produced, and on the type of equipment used.

A good example of the more modern techniques in large-scale TV production is provided by the BBC Television Centre mentioned earlier; for this very large building, first opened for use in June 1960, presents the latest advances in TV engineering and architecture, its design being based on experience gained over more than 25 years of television broadcasting. The Centre is the nucleus of the entire TV organization of the BBC. From it are produced, or through it are routed, all the signals destined to be broadcast from its nation-wide transmitter network.



The **television studio** itself varies widely in size, in function, and in the complexity of its technical equipment. It may be anything from a small room from which a news broadcast or a programme announcement is made or in which a personal interview is conducted, to an enormous stage holding scores of performers, masses of scenery and a bewildering array of complicated equipment.

In the smaller studios the number of cameras and microphones used will rarely exceed two; whereas in a large-scale production studio it is by no means uncommon for half-a-dozen cameras, and an even larger number of microphones, to be in use at any given time.

The number of technical staff engaged on a TV programme depends, of course, on its complexity; and also on whether it is being transmitted "live", as opposed to having been pre-recorded on video-tape or film for later transmission. A news broadcast, for instance, involving only a single announcer and perhaps a small number of filmed "shots", often makes use of pre-aligned cameras which are completely unmanned and electrically controlled from a remote position. It therefore needs the services of very few controlling staff.

On the other hand, the live presentation of a programme involving many different scenes, scores of performers, constant lighting changes and so on, will call for much planning, a great deal of rehearsal, and a large number of technical and artistic staff.

Telecine and Video-Tape Machines

Quite apart from signals coming into Television Centre from external sources—outside broadcasts, for example, and other studios both at home and abroad—the producers of a TV programme are not confined to using only the scenes they themselves create on the studio floor. There are, within the building itself, other sources of material on which they can draw when they want it.

Two of these sources deserve mention. Essentially, they are both specialized pieces of recording apparatus, called respectively the *telecine machine* and the *video-tape machine*. They are permanently housed in a separate **telecine suite** in Television Centre, but can be switched on and off from the main Studio Unit (*see next page*) as and when required. Here is how they are used.

The **telecine machine** converts ordinary cinematographic film into a sequence of the equivalent electrical signals, and delivers these signals when they are required for use. There are many types of scene (a large aircraft coming in to land is a good example) which obviously cannot be reproduced in the studio. The necessary shots must be filmed beforehand. When the picture of the landing aircraft is required in the production being televised, the telecine machine is switched on from the studio, the relevant length of film is processed in the machine, and the corresponding sequence of electrical impluses is fed at the appropriate point into the signal to be radiated.

The **video-tape machine** works rather like the ordinary tape-recorder which you use to record a programme on the radio, or your own or your friends' voices, for later playing-back at your leisure. Instead of recording audio signals, however, the video-tape machine records on tape the *video* signals produced by a TV camera. This is usually one of the cameras being used on the studio floor, but there is no technical reason why it should not be an outside-broadcast TV camera instead.

The sort of circumstance in which video-tape would often be used is in recording scenes in the studio which are to be artificially compressed in time in the televised programme. Imagine a comic sequence, for instance, of a man waking up late for work—leaping bleary-eyed out of bed, stumbling into the bathroom, gobbling some breakfast, dashing back because he has forgotten to kiss his wife good-bye, and then running like mad for his bus or his train! The whole sequence might be effectively presented on the TV screen within the space of thirty seconds. No actor could possibly enact it "live" during so short a period; so the various "bits and pieces" are pre-recorded on video-tape and fed into the final programme as required.

Another use for video-tape is in the recording on tape of the electrical signals corresponding to a complete TV production, for re-broadcasting from another (possibly foreign) studio, or at a later date.

Video-tape is quickly taking over much of the work hitherto recorded on photographic film in the studio, or in "semi-fixed" installations outside. For work in the field, the greater portability of the photographic camera still gives it a big advantage—the film exposed being later converted into electrical signals by the telecine machine.

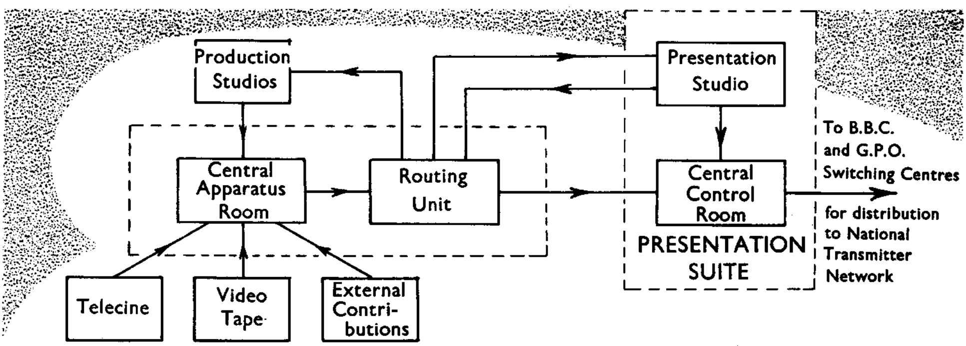
How Programme Signals are Routed

There are in BBC's Television Centre (in addition to a large number of studios of smaller size) seven major **Production Studios,** each designed to function as an independent unit. It will be useful to trace the path taken by signals originating in one of these production studios before they leave Television Centre on their way to the Switching Centres in Central London.

Whatever their original source, all the sound and vision signals selected for transmission are passed to a **Central Apparatus Room**, which is the principal collecting point for all the signals intended to form part of the programme. In this Central Apparatus Room is housed much other technical equipment needed in the production, particularly the gear producing the synchronizing pulses for the cameras which you will read about very shortly.

From the Central Apparatus Room, signals are fed through a **routing unit** to a **Central Control Room,** whose function is to maintain the continuity of the many programmes produced during the day's transmission, and to control the distribution of these programmes to the national transmitter network through the BBC and GPO Switching Centres.

This Central Control Room itself forms part of what is called a **Presentation Suite,** the other unit of which is a small **Presentation Studio** from which will often be televised programmes of the straightforward interview type, and also many of those scenes in which a personable announcer describes to the TV audience the attractions of the programme to follow.



BBC Television Centre PROGRAMME ROUTING SYSTEM

The Studio Unit

Every one of the seven major production studios in Television Centre contains its own studio floor, and all its own technical control facilities. Essentially, each studio unit contains four main areas:

(1) The Studio Floor

(2) The Production Control Room

(3) The Lighting and Vision Control Room

(4) The Sound Control Room

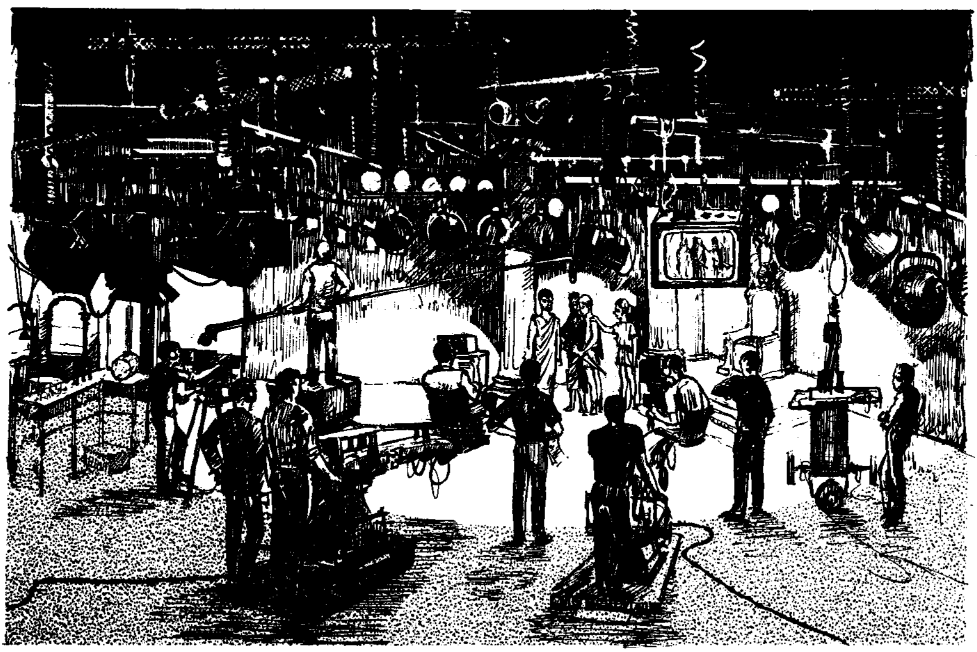
The Studio Unit—The Studio Floor

This is a very large, almost factory-like, room—typically as much as 100 ft. long, 80 ft. wide, and 40 ft. or more in height. Slung beneath the ceiling of this enormous chamber, and running from side to side of it down its entire length, are a series of specially-shaped girders, supporting rails, brackets and the like, from which there hang and along which there slide a vast array of powerful lamps, pendant microphones, scenery and technical equipment of many kinds.

Round the walls there will be set up a number of different stages, each complete with the scenery needed for a particular scene in the production being televised, and each awaiting only the actors to enter and speak their lines. The central areas of the floor will be largely occupied by a number of bits of machinery resembling hand-propelled tractors of different shapes and sizes, all mounted on rubber-tyred wheels and all having perched on their backs or sides shirt-sleeved technicians controlling cameras or swinging into position microphones hanging from long movable booms.

On the floor itself there will be cables—hundreds of yards of cables of every size—cables connecting lights, cameras, microphones and technical equipment of great variety to their respective power supplies and control points.

Carefully picking their way over this tangle of wires and between the array of "mobile machinery" will be people—actors, scene-shifters, camera and microphone crews, lighting and power technicians, secretaries, and the immediate staff of the **Studio Manager** himself. No rule can be laid down about the numbers of artistic, technical and other staff likely to be present on the studio floor at any one time. Like the quantity of scenery and of assorted lighting and electronic equipment used, all will depend on the nature and scale of the production being staged. For a really large production such as (say) a big court-room scene, a total of 50 people present at the same time on the studio floor would not be unusually large.

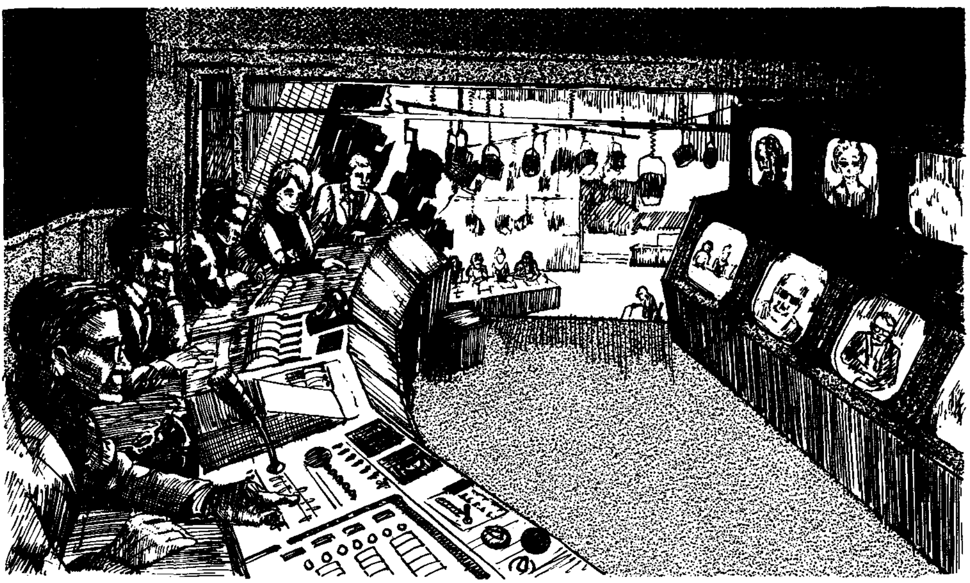


The Studio Unit—The Production Control Room

The Production, Lighting and Vision, and Sound Control Rooms are situated side by side at first-floor level at one end of the Studio Floor, with the **Production Control Room** in the middle. Each room has a large sloping observation window through which the controlling staff can see all that happens on the studio floor, and internal windows through which the Producer can signal to the other two rooms.

The **Producer** himself is the man (or woman) who is in overall command of the whole Studio Unit while the particular production of which he is in charge is on the floor. From his seat at the Production Desk he controls in detail the way in which the production is to be finally presented to the viewer, choosing which of the pictures being produced by the cameras on the floor (there may be up to six of them on occasion) are best suited to the script at any moment, cutting in to them (maybe) pictures from sources outside the studio. This he may either do himself by the manipulation of a bank of electrical controls mounted on the desk before him; or (as is more usual) he may delegate the task to a person called the **Vision Mixer,** who then sits beside him.

Assisting him in his task, and also sitting at the Production Desk alongside him, are his **Secretary,** who checks timing and calls out camera "shot" numbers; and the **Technical Operations Manager,** who is responsible for all the technical aspects of the production.



Between the producer's team and the studio floor, a telephone "intercom" system makes it possible for instructions to be conveyed to the studio manager, to the microphone operators or to the camera-men at any time during the production.

Standing in front of the production desk is a bank of nine 21-inch screen **picture monitors.** Every camera on the floor has its pictures displayed by one of these monitors; while others display pictures derived from outside the studio. The ninth monitor displays the **final transmission picture**—that is, the actual picture which the producer has selected for transmission out of all the pictures displayed on the other monitors.

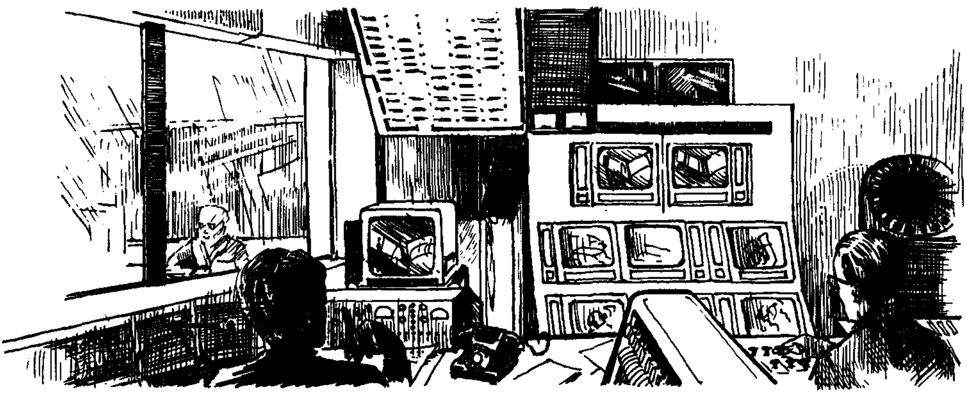
The Studio Unit—The Lighting and Vision Control Room

In this second of the three Control Rooms, the **Lighting Supervisor** is responsible for controlling all the lighting arrangements in the studio; and the **Vision Supervisor** for controlling the technical quality of the pictures produced by the studio cameras. These two operations are closely related technically, which is why the two supervisors share the same room.

The two control desks are placed side by side in front of a bank of eight picture monitors displaying the pictures produced by the studio cameras. A ninth monitor stands on its own, and displays the final-transmission picture to the Lighting Supervisor alone. Of the eight monitors in the bank, up to six are linked to individual cameras on the floor; a seventh shows the final-transmission picture selected by the Producer in the next room; while the last is used for displaying pictures derived from outside the studio, which are about to be used in the programme. This last monitor can also be made to display pictures appearing on the camera monitors one after the other, in sequence. This greatly helps accurate matching of picture qualities, and ensures that false information derived from a defective monitor shall be detected before action is taken on it.

Alongside every picture monitor, a narrow rectangular CRT displays the picture signal waveform produced by the camera associated with that monitor. This display helps the Vision Supervisor to maintain the black-level reference of the picture signal at its correct value.

In front of the Vision Supervisor are six camera controls arranged in the same pattern as the six camera monitors, each control governing one camera down on the studio floor. By moving the appropriate control knob *sideways* along a quadrant, the Supervisor can adjust the lens aperture of any camera, thereby varying the light input to it. By *rotation* of the knob, he can alter the black-level setting of the picture signal waveform produced by the camera. By *depressing* the knob he can switch that camera's picture from its usual monitor on to the one used for comparison and matching.



In the **Sound Control Room,** the Sound Supervisor has a desk from which he can control all the studio microphones; and also record-players, tape-recorders and special sound effects derived from outside the studio itself. This desk is positioned close to the observation window; and from it he can at all times see the position of every microphone on the studio floor. Should any microphone begin to be visible on the two picture monitors which he has in front of his desk, he can at once warn the operator over the intercom to move it out of the way.

The Camera Chain

One of the advantages of the modern TV camera is its manœuvrability. This manœuvrability can be effectively increased in two ways: by stripping the actual camera of every piece of accessory equipment which can possibly be put elsewhere; and by freeing the operator from all possible duties which could interfere with his primary job of getting his camera into the best position all the time it is in use.

To achieve these aims, there has been devised an arrangement called the **Camera Chain.** Every TV camera when it is in use will nowadays form part of a camera chain; and no matter how many cameras are being used to record a production, each will require its own separate chain of ancillary equipment. All the parts of this chain, wherever situated, will be electronically interconnected as long as that particular camera is in use; and if one of the parts of the chain should fail, the whole of it will become unserviceable until the defective part can be repaired or replaced.

There are five major links in a camera chain. They are:

i) **The master sync pulse generator** situated in the Central Apparatus Room;

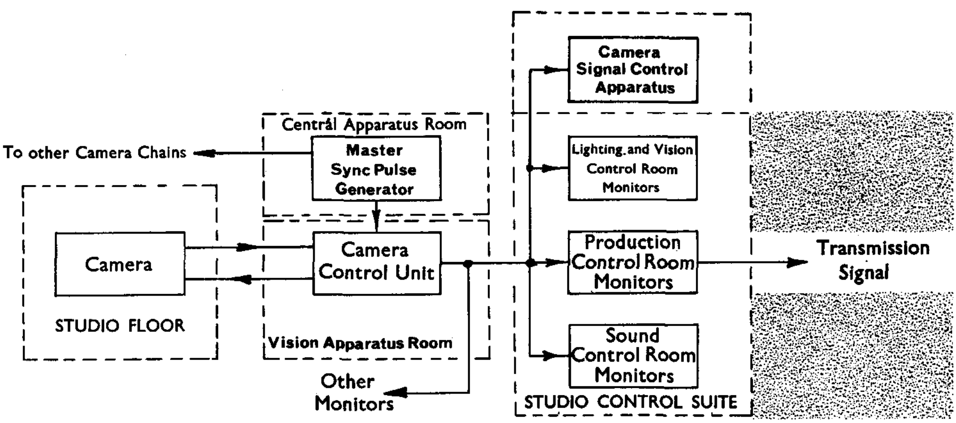
ii) The **camera control unit** (normally abbreviated to **CCU**) situated in the Vision Apparatus Room;

iii) The **camera** itself and

iv) The **camera monitors,** which you already know about;

v) **Camera signal control apparatus** normally situated in the Production Control Room and in the Lighting and Vision Control Room. Its purpose is to enable the Producer and the Vision Supervisor to take effective action on the basis of the information presented to them by the camera monitors.

The general layout of a camera chain is shown in block diagram form in the illustration below. Remember that the purpose of this seemingly-complicated and expensive layout is to permit all possible technical assessment and control of camera performance to be exercised by specialists operating well away from the camera itself, so freeing the camera operator for his main job of keeping his camera accurately trained on the part or parts of a scene for which he has been made responsible.

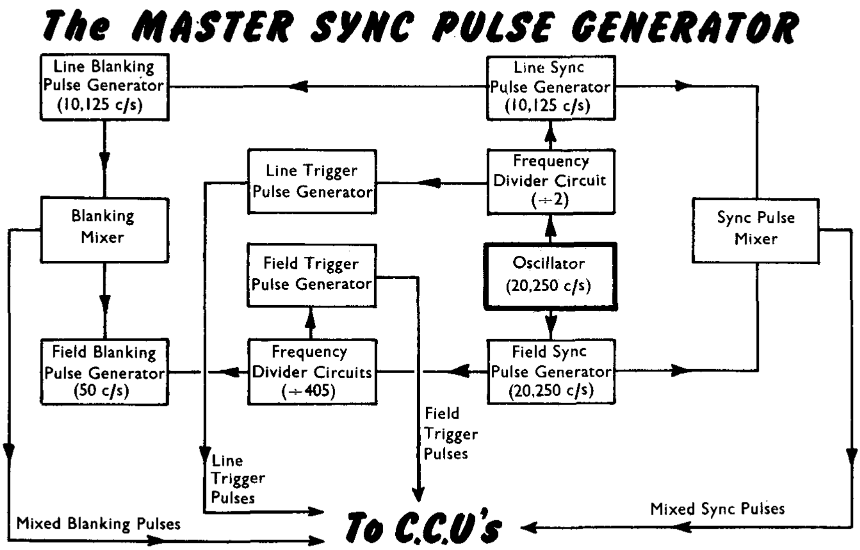


The Master Sync Pulse Generator

It is the task of this very important piece of equipment to supply all the blanking, triggering and synchronizing pulses required by all the cameras and other pieces of equipment which are operating on a given line-system throughout the Television Centre. There are thus two master sync pulse generators operating in the White City TV Centre—one for the cameras, etc., working on the 405-line system, and another for all the equipment working on the 625-line system.

The object of having all these essential, but "non-picture-signal", pulses supplied from a common source is to aid synchronization of all the equipment working on a particular scene. It frequently happens that the producer wants to use more than one camera, or even more than one signal source, as he builds up his presentation of the tale he is telling, and to feel free to jump from one signal source to another as he goes along. The chances of accurate synchronization are plainly improved if the various timing signals all come from a common source.

The illustration below shows the block diagram of a master sync pulse generator controlling the equipment of a 405-line-system camera chain. The sync pulse generator controlling a 625-line camera chain operates in much the same way, but is rather more complicated in view of the need to generate the equalizing pulses (see Section 5).



The heart of the master sync generator is a very stable oscillator, whose sinewave output is made rectangular by being passed through a selection of the pulse-shaping circuits you learn about in *Basic Electronic Circuits*, Part 1. This is done within the block marked "oscillator" in the illustration.

The operating frequency of the oscillator is always *twice the frequency at which the line sync pulses recur* in the particular TV system in question. Operating frequency is therefore, 20,250 times per second in the 405-line system, and 31,250 times per second in the 625-line system (twice the number of lines per field multiplied by 50 fields per second). A basic frequency of this value is needed in order to provide the "raw material" for the half-line pulses of the field sync pulse, and for the equalizing pulses also needed by the 625-line system only.

The Master Sync Pulse Generator (*continued*)

The shaped pulses from the oscillator block are fed in two directions. In the first path, they go to the *field sync pulse generator*, which produces the half-line pulses making up the field sync pulse.

These half-line pulses, in turn, take two paths. The first takes them through frequencer divider circuits of the type you met on page 1.79 of *Basic Electronic Circuits*, to trigger the *field blanking pulse generator*. The output of this generator is required to suppress the electron beam during field fly-back. It therefore needs to be a sequence of pulses recurring at a frequency of only 50 Hz. Thus the frequency of the half-line pulses needs to be reduced in the divider circuits by a factor of 405 in the 405-line system, and in the 625-line system by a factor of 625. You learnt in *Basic Electronic Circuits* that the maximum practical limit of the synchronized multivibrator was about a ten-to-one count-down. To achieve a 405-times count-down therefore means that the half-line pulses have to be passed through three count-down circuits in succession, achieving frequency division of 9, 9 and 5 times respectively.

The field blanking pulses, when formed, are fed to a *blanking mixer* stage where they are mixed with the line blanking pulses whose source you will be tracing in a moment.

The 50 Hz output signals from the frequency-divider block are put to two other uses. In both systems, they are made to generate triggering pulses for the *field scanning circuits* in the respective CCU's (see next page); and in the 405-line system they are also fed to a frequency-control circuit (not shown on the block diagram opposite) whose job is to compare the frequency of the 50 Hz pulses with that of the mains supply and, if a difference develops, to generate a controlling voltage which brings the two frequencies back into synchronism by correcting the frequency of the master oscillator itself. (No such frequency-control arrangement is needed in the British 625-line system because of the improved circuit techniques which were available when the system was designed.)

Back, now, to the field sync pulse. This pulse must recur, as you know, fifty times a second and consists of a group or cluster of shorter (half-line) pulses varying with the line-system concerned. The second job of the field sync pulse generator is therefore to marshal the half-line pulses it produces into the appropriate clusters, to add to them (in the 625-line system) the equalizing pulses, and to feed the field sync pulses so formed to a *sync pulse mixer* stage for mixing with the line sync pulses.

Now for the generation and routing of the *line blanking* and *line sync pulses*.

In the second signal path from the oscillator block, the signal is fed to a count-down circuit which divides its frequency by two, to produce a signal at the line frequency appropriate to the line-system (405 or 625) concerned. The first output from this circuit is used to generate the trigger pulses needed by the *line scanning circuits* in the respective CCU's; the second goes to the *line sync pulse* generator.

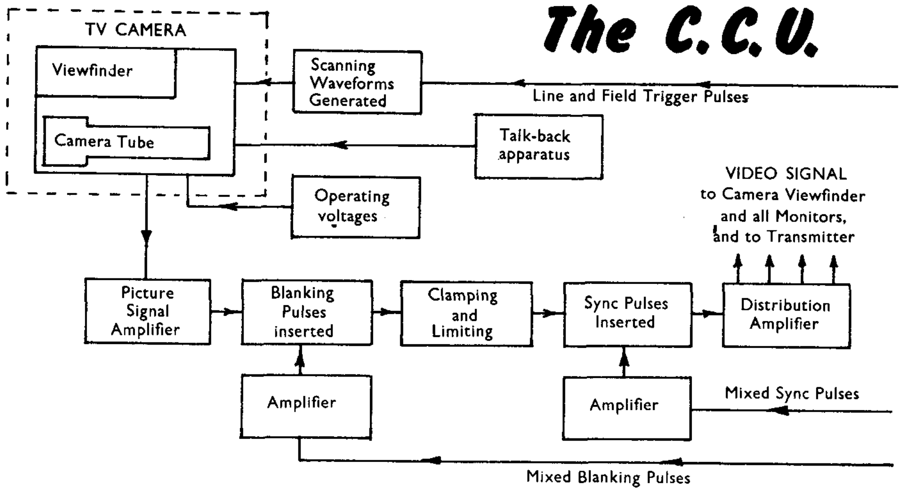
The output of this generator is the stream of very short-duration pulses required to trigger the line scans in the camera (and, later, in the picture tube of the receiver). It again splits into two. The first output goes to the sync pulse mixer; the second to the *line blanking pulse generator*. In this block, the line pulses are shaped to the duration and amplitude required for their beam-blanking function during line flyback, and are then sent to join the field blanking pulses in the blanking mixer stage.

The much-simplified block diagram of the Master Sync Pulse Generator on the page opposite shows, finally, how the mixed blanking pulses, the mixed sync pulses, and the line and field trigger pulses are all distributed to their respective CCU's, and to the other pieces of apparatus in the TV Centre which will need to use them.

The Camera Control Unit (CCU).

Whereas the master sync pulse generator is common to all the camera chains working on a given line system throughout the TV Centre, there needs to be a separate CCU for every camera employed.

The CCU is housed (as you know) in the Vision Apparatus Room which forms part of every studio unit. It provides the operating voltages needed by the camera and by several other pieces of equipment in the camera chain. Most of its other functions can be seen in the block diagram below.



You will see, at the top of the diagram, where the line and field trigger pulses from the master sync pulse generator initiate the scanning waveforms for the camera. Next, moving downwards from the camera, you see the picture signal being amplified, and then having inserted into it in turn the mixed blanking pulses and the mixed sync pulses from the master sync pulse generator. In between these two insertions is a block in which the signal may be clamped to a suitable black-level reference, and will have restored to it the d.c. level lost in the camera coupling circuits when the signal passed through the picture signal amplifier.

The complex *video signal* resulting from all these operations is further amplified in the distribution amplifier, and is fed to the viewfinder of the camera and all the other monitors attached to its camera chain. It is also, of course, sent on its way towards the distant transmitter, if it happens to be the one selected by the producer to tell that particular part of the story.

Other functions of the CCU are to provide the one-way *talk-back* and *cueing* apparatus whereby the production control staff can pass instructions to the individual camera operators, and to perform a number of technical operations on the video signal before it is distributed—mainly with the aim of making it as free from distortion as possible, and of the correct amplitude relative to the amplitude of the sync pulses.

The Camera Signal Control Apparatus

The several pieces of equipment which go to make up this apparatus allow the producer to bring into play several of the various camera techniques described on the next few pages, and his technical assistants to keep check on the quality of the picture signals produced by a given camera and to adjust the quality of these signals when necessary.

Camera Techniques

Many of the special techniques used in the studio to help the smooth presentation of a television scene go completely unnoticed by the average viewer. You should know, in outline, what some of these techniques are, what they are used for, and how they are achieved.

Cutting

Imagine that you are sitting facing two people in your own home, and listening to their conversation. As each one speaks in turn, your eyes normally turn automatically to the speaker as you listen to what he or she is saying; and then flick equally automatically to the face of the other as he starts to reply. It may sometimes happen that one wants to watch the face of the *non-speaker* to observe his reactions to another's speech—as when, for instance, a detective is watching a suspect being questioned at a police station—but the point is that the face which one wants to be watching is seldom the same one all the time.

Now suppose two people are being televised holding a similar sort of conversation. Your eyes will now be replaced by a camera—and ultimately by a viewer watching from many miles away. If this viewer is to follow the conversation as intelligently as you did earlier, he too will want to turn his eyes to the face of principal interest—nearly always that of the person speaking—as the conversation ebbs and flows. Since he cannot do this for himself, the producer must do it for him. How?

The way it is done is to have two TV cameras, each focused on to one of the people being televised, and each operating all the time. In the Production Control Room, the producer watches the two pictures produced and selects the one he thinks most interesting at any given moment, constantly switching from one face to the other as the conversation proceeds. This switching from one camera to another must be instantaneous, with no sign of the blur which would result if a single camera were to swing back and forth from one person to another as the scene unwinds.

This form of instantaneous switching is called **cutting,** and every separate switching operation is called a **cut.** The producer achieves a cut by depressing a button on a panel in front of him, which selects the wanted signal.

Fade

There are two kinds of fade used in the telling of a TV story—**fade-out** and **fade-in.** The first is commonly used to mark the slow, almost reluctant, ending of the action in one phase of the story; the second to usher in the beginning of a new episode. You could almost say that fade-out is one of the TV producer's ways of ending a chapter, and fade-in one of his ways of starting a new one.

Fade-in and fade-out are achieved by slowly increasing or decreasing, respectively, the amplitude of the picture signal produced by the camera recording the scene. Control of this operation will be exercised directly by the producer or by one of his staff in the Production Control Room—not by the camera operator himself. The *fader control* is essentially a potentiometer controlling the amplitude of the picture signal content of the video signal sent to the Central Apparatus Room for transmission.

The overall duration of a "fade-out/fade-in" between consecutive scenes will seldom exceed ten seconds, and will typically be about half that period of time.

Camera Techniques (*continued*)

A **dissolve** is the technical name given to an operation which consists of a fade-out from one camera and a fade-in to another one recording a different scene. By deft control of the relative picture signal amplitudes of the two cameras, the pictures they produce can be made to merge, or dissolve, into one another, until finally one picture supersedes the other altogether.

A typical application of a dissolve would be the shot of an aeroplane taking off from a runway, merging into a scene showing the passengers inside the aircraft unfastening their safety belts once the plane has gained safe height. A smooth transition is thus effected to a subsequent episode of the story—generally to one taking place after the elapse of an uneventful interval of time.

A normal dissolve would last for some five or six seconds from start to finish.

Defocusing

This operation achieves much the same purposes as a dissolve, and is done by slowly defocusing the camera recording one scene as the scene recorded by another camera is equally deliberately faded in.

Defocusing is achieved by altering the setting of the camera lens in relation to the target of the picture tube. With some types of camera this can be done directly from the Production Control Room via the CCU; but it is usually controlled by the camera operator on the studio floor under instructions transmitted to him by the producer over the "talk-back" apparatus already described.

Panning

This is the name given to the slow revolution of a camera on its swivel base as it records in turn (let us say) the expressions on the faces of a jury as they take in the significance of a dramatic piece of new evidence.

and a PANNING Shot

Results on the Viewer's Screen

A camera so revolving is said to be **panning.** The picture recorded by it as it revolves is called a **pan shot.**

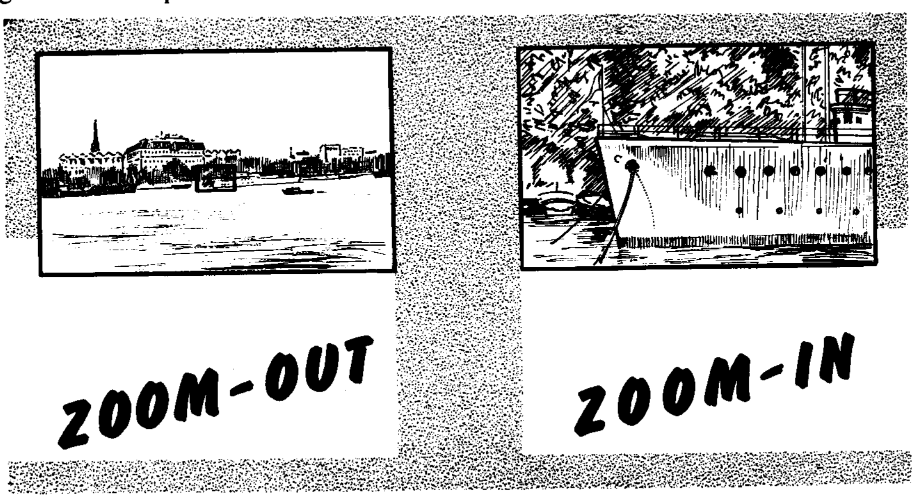
Camera Techniques (*continued*)

The normal way of producing in the studio a gradual **close-up** of part of a scene first viewed from a distance is to move a camera slowly towards the scene until it is close enough to produce the desired effect. This is generally done by pushing the camera *dolly* (the rubber-tyred trolley on which the camera is mounted) silently by hand into the required position.

In outside broadcasts, however, or in situations in which permissible camera movement is restricted (*e.g.*, the recording "live" of an opera at Covent Garden), the close-up desired by the producer is achieved by the gradual expansion of a powerful lens system mounted in front of the lens of the camera itself. Such a system is known as a **zoomar lens.** It is only fair to warn you that you will not fully understand the brief account of it which follows unless you already know the meaning of a few basic photographic terms.

There are three separate lenses in a typical zoomar system, mounted in line with only the centre lens movable. The fixed front and back lenses are of the *positive convergent* type, the movable centre lens of the *negative divergent* type. When the centre lens is moved towards the front lens, the lens system acquires a longer effective focal length, and the effect of close-up (or *zoom-in*) is achieved. When the centre lens is moved backwards towards the rear lens, the effective focal length is reduced and *zoom-out* results.

An important advantage of the zoomar lens is that although the apparent size of the object viewed can be made to vary with the degree of zoom-out or zoom-in, the ratio of focal length to lens diameter (the *f number* of the lens system) remains unchanged. This means that the lens aperture does not have to be altered as zoom-in proceeds, and the brightness level of the object being viewed does not vary with the degree of close-up.



Tilt

The eye of a camera leaves street level and slowly travels up, *up*, *UP* the vertical flank of a skyscraper in New York City, until it comes to rest at last on the immensely foreshortened uppermost floors silhouetted against the sky. . . .

This operation is known as a **tilt.** It is effected by the camera operator himself. The need to take tilt shots when required is one of the reasons why a modern camera needs to be very carefully balanced on its swivelling base.

Camera Techniques—Special Effects

Three types of special effects developed in the cinematograph industry are being put to increasing use in TV. They are **back projection, inlay** and **overlay.** Collectively, they are sometimes called **montage effects.** The object in each case is to persuade the viewer that something is happening on his screen which it would be either difficult, impossible or very expensive to photograph direct.

In the **back projection** technique (it is also known as *process projection*), either an ordinary cinema projector or a "magic lantern" is set up behind a translucent screen and is made to project on to it either a moving or a still image of a desired piece of scenery. The actors perform in front of the screen, and the TV camera field takes in not only them and any foreground "props" which the action requires, but the projected background as well.

In this way it is possible to fake pictures of a man talking to a girl in the front seat of a moving car with the road unwinding behind them, or of the same man posing with the same girl in front of the Taj Mahal, without (in the first case) mounting a backward-pointing camera on the bonnet of a moving car or (in the second case) sending man and girl, plus technicians and much heavy equipment, all the way to India.

Difficulties of the back projection technique include the following:

a) It takes up a lot of space on the studio floor.

b) The translucent screen must be very powerfully lit so as to acquire a level of brightness which the TV camera can use; and this brightness must be uniformly spread over the whole screen surface.

c) Noise from the projector must be so low that the microphones recording the main action will not pick it up. Projector noise includes the whirring of a moving-picture camera, and the hiss of the escaping air blast commonly used to cool the slide of a "still" projector.

Lighting difficulties are the most serious; for if light from sources other than the projector (*spill light*, as it is called) is not kept to a minimum, the average brightness of the projected image will be too low to "look right" to the TV camera. The problem is particularly acute in the first few feet immediately in front of the screen.

You will see that back projection is essentially an optical means of combining the output of two cameras, or of one camera and one "still" projector. Inlay and overlay are electronic methods of doing the same thing.

Camera Techniques—Special Effects (*continued*)

Inlay is a technique used for combining the outputs of two signal sources in such a way that, in the composite picture shown to the viewer, *the foreground scene replaces the background scene over certain areas of the latter which remain fixed throughout the process.* Here is how it might be used in the shooting of a TV adventure story.

At a time of national crisis, the President of Ruritania steps out on to the balcony of his palace to make a pronouncement to the anxious crowds below. The distinctive façade of the Presidential Palace is known throughout Europe; and it is undoubtedly that façade which you are watching as the President speaks. How, short of hiring the palace for the day from its present incumbent, has the scene been shot?

What happens is that one camera (or a telecine film scanner) will be kept throughout the speech trained on to a library photograph or slide of the palace itself. Elsewhere in the studios a second camera will be focused on to a facsimile balcony standing on an empty stage, from which the actor impersonating the President will deliver his oration. The outputs of the two cameras will then be matched in the Production Control Suite in such a way that the balcony, and the President within it, will appear anchored in its correct location on the palace wall.

The principal drawback of the technique would arise if the "President" were to be so carried away by his own eloquence as to move outside the strict limits of his stage balcony. Not only would he then appear to the viewer to begin moving crabwise and without visible means of support across the vertical façade of his palace. He would also turn into a semi-transparent ghost as he did so.

The reason is, of course, that the background signal would no longer be suppressed as the foreground signal moved over it. Instead, both signals would appear simultaneously on the viewer's screen.

The inlay technique is thus a means of cutting what amount to "electronic slots" in certain fixed areas of the background scene, and of fitting into these slots appropriate bits of separately-photographed foreground scene. In briefest outline, it is done by placing an opaque mask between a short-afterglow CRT of the type used for film scanning, and a photo-multiplier type of photocell. The mask has a cut-out of the correct size and shape, and in the correct area, to hold exactly a foreground shot of the President gesticulating on his balcony. The scanning beam of the CRT is synchronized with the scanning beams of the two cameras. When the beam is scanning areas obscured by the mask, the photocell receives none of the glow of the CRT, and the signal produced by the camera recording the *background* scene goes forward for transmission.

When the beam of the CRT moves into the area of the slot, however, the photocell picks up its glow and at once produces what is called a *silhouette pulse*. This pulse operates an electronic switch, whose function is to select for transmission only the picture signal produced by the camera recording the *foreground* scene—and that only for as long as the silhouette pulse is present at the switch. In this way, only one signal at a time is accepted from the two picture-signal sources.

Camera Techniques—Special Effects (*continued*)

An interesting example of the inlay technique allows a whole range of effects to be produced by the use of *false perspective*. In this way, the miniature figure of a girl can be made to dance on top of a piano played by a pianist of normal size, or a giant can be made to inhabit an ordinary house by having his blown-up head "slotted in" so that it looks out of one of the windows.

Another adaptation of the technique enables any desired type of transition to be made from one scene to another, with the second scene superseding the first as a line of demarcation passes gradually across the screen. This is known as a **wipe,** and is achieved by passing a mask of the desired shape across a small optical image of the scanning raster.

Overlay is essentially similar in the results it produces to back projection. The difference is that it uses electronic means of placing a desired background behind an "acted" foreground, whereas back projection uses optical means of doing so. Overlay, however, can provide a greater range of effects than can back projection, and it has the advantage of not requiring a translucent screen or the space taken up by a back projector. All it needs is a plain screen either totally unlit or else more conveniently lit from in front.

There are several ways of achieving overlay, but in all of them a signal representing a moving outline of the foreground figure (in effect a more complex type of silhouette pulse) is made to operate an electronic switch. The switch selects the background signal from Camera 1 until a silhouette pulse arrives, when it selects instead the foreground picture from Camera 2 as long as the pulse is present.

The actor performs in front of a plain screen, which may be either white or black. A particularly wide range of effects can be produced when a black background is used. For instance, if the actor's face, neck and hands are swathed in black cloth, and if the lighting is so arranged that they will not be visible against the black background, an empty suit of clothes can be made to walk about a room and a very creditable Invisible Man produced on the screen.

What has happened electronically is that the silhouette pulse which would normally have been generated as soon as the scanning beam encountered (say) the actor's face has been literally "bluffed out of existence", with the result that the background signal is transmitted in its place—and the picture over the mantlepiece appears unobscured between the Invisible Man's collar and the brim of his hat!

Camera Techniques—Video Effects

Other special effects can be produced in TV by other electronic means. An example is the deliberate exaggeration of the contrast range of the picture produced by a camera, by manipulation of its appropriate amplitude control.

A troupe of dancers, let us say, is performing on a dimly lit stage. They are all wearing black make-up or black face masks, and all are dressed in black from head to foot save for a pair of white gloves each. By slowly reducing the ambient lighting and simultaneously increasing the amplitude of the video signal, the swinging white gloves can be made to stand out more and more against a steadily darkening background, until the very movement of the dancers themselves become invisible and only the white gloves swing and swing. . . . .

§ 7: THE TRANSMITTER AND AERIAL

Once it has left the TV studio, the video signal passes through the various Switching Centres you learnt about in the last Section, to the transmitting station situated from a few to several hundred miles away. It is accompanied by the audio signal.

By no means all TV transmitting stations are equipped to radiate television signals only. Many serve as combined TV and sound-radio broadcasting stations, with the sound side radiating a frequency-modulated carrier of very high frequency (*i.e.*, a "VHF/fm station"). Such a combined station will often be radiating as many as three different radio programmes as well as a single TV programme. Both the TV and the radio transmitters will be installed in the same building; and will be supervised by the same team of engineers, assisted by automatic alarm devices common to both transmitters.

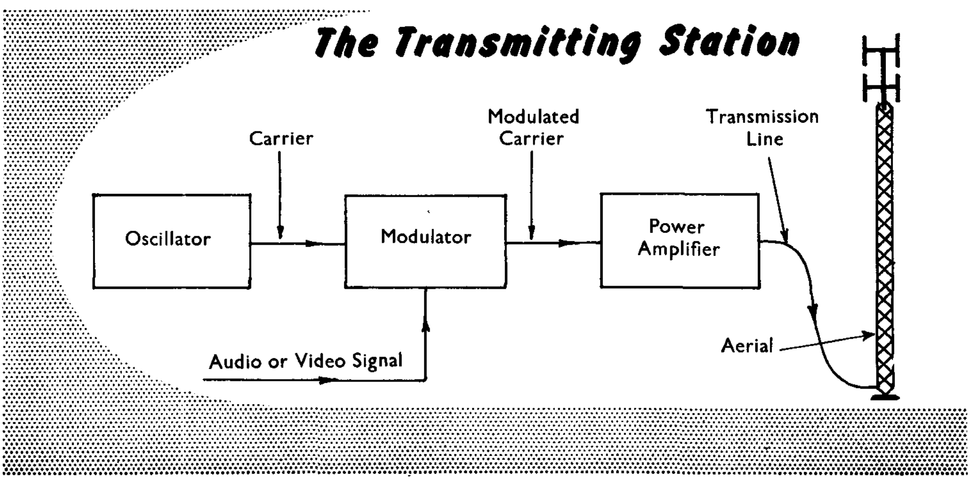
The TV side of such a composite transmitting station will itself comprise at least two separate transmitters—one to handle the video signal and the other to handle its associated audio signal. The two transmitters will be situated close together, often side by side. Their outputs will be the **vision signal** and the **sound signal** respectively.

These two signals are then usually combined in the last stage of their processing in the transmitter building, and are taken over a common transmission line to the aerial, from which they are radiated as a combined signal to the distant viewers.

You will remember from what you read in Part 4 of *Basic Electronics* that, before you can radiate over any distance waveforms of voltage or current such as those which are produced by a microphone or television camera, you must first *convert the waveforms into high-powered radio-frequency signals.* These r.f. signals must then be *propagated as electromagnetic waves.*

The first of these tasks is performed by the **transmitter,** the second by the **aerial.** Together, these two elements make up the **transmitting station.**

Both sound and vision transmitters work on much the same principles. The transmitter consists of a very stable *oscillator* which produces a high-frequency carrier wave of fixed frequency and amplitude; of a *modulator* stage in which the signal is combined with the carrier in such a way as to modulate either its frequency or its amplitude; and of a *power amplifier* in which the modulated carrier is raised to a power high enough for the aerial to be able to propagate it to the desired range.



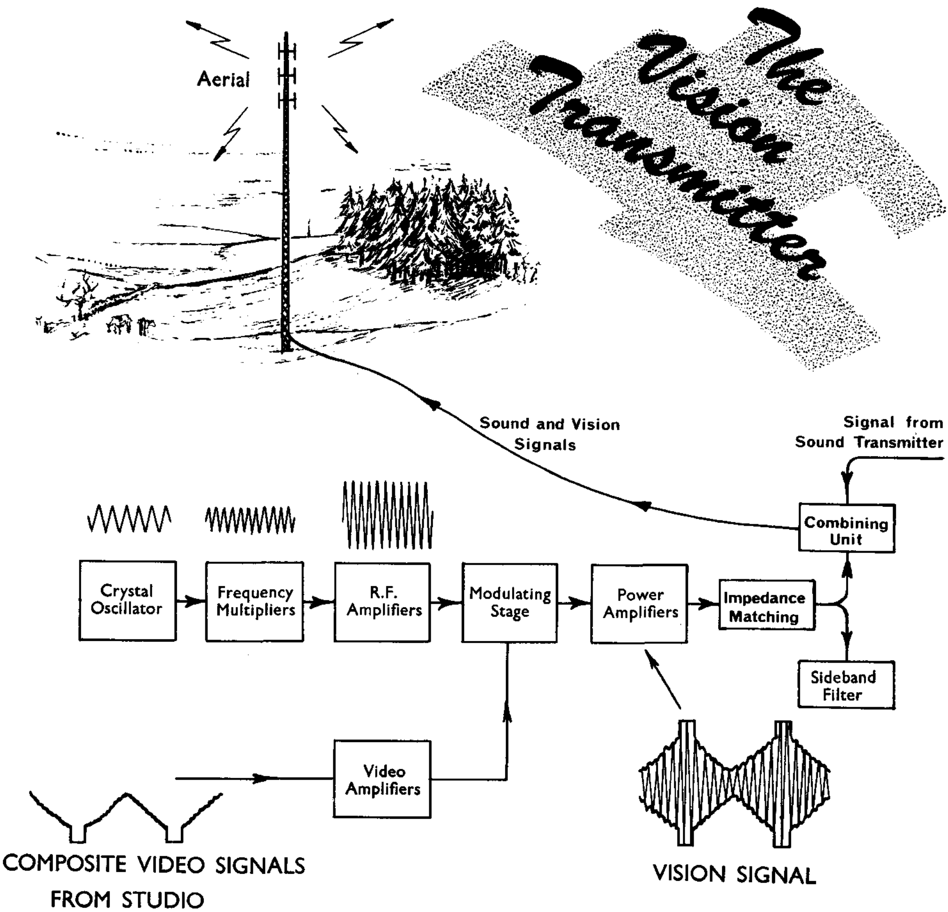
The Vision Transmitter

The illustration below sets out in block diagram form the essential features of a typical vision transmitter.

The first stage in the transmitter will normally be a highly stable **crystal-controlled oscillator** circuit. It is important that the carrier wave be maintained at a very stable frequency, both for reasons of general transmitter efficiency and so that the frequency of the radiated signal shall be maintained at its assigned value throughout the period of transmission.

It is generally easier to control an oscillator operating in the VHF range when the frequency is kept as low as possible. For this reason, the frequency of the crystal-controlled oscillator is arranged to be *lower* than the frequency at which it is intended to radiate the signal.

The frequency of the "basic carrier" is then stepped up to the intended operating frequency of the transmitter by means of one or more **frequency-multiplier** circuits such as those you studied in *Basic Electronics*, Part 4. These circuits, as you know, are capable of producing an output whose frequency is *an exact multiple* of the frequency of the input. Since this input frequency was highly stable in the first place, the stability of the stepped-up frequency will be maintained without impairment.

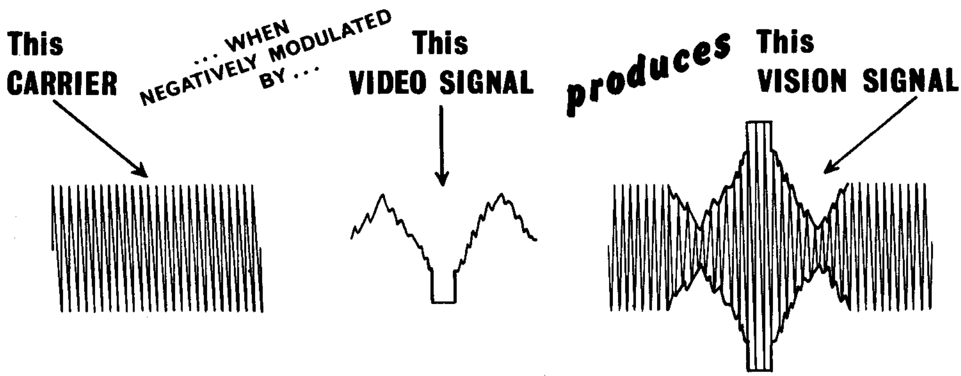


The Vision Transmitter (*continued*)

The carrier emerging from the frequency-multiplier circuits is then amplified to a level suitable for modulation by being passed through one or more **r.f. amplifier** circuits; and is then fed to the **modulating** stage.

Also fed to this modulating stage, after considerable amplification in a number of **video amplifying circuits,** are the composite video signals reaching the transmitter by high-quality coaxial cables (or, in some cases, by SHF microwave relay) from the switching centres and the TV studio.

The effect of applying to the same stage both the varying voltages of the video signals and the r.f. carrier with its highly stable frequency and amplitude is *to make the amplitude of the carrier vary in exact accordance with the variations occurring in the amplitude of the video signals.* The effect is shown in the illustration below.



The vision signal resulting from the above process is, of course, none other than an amplitude-modulated wave of the type with which your work in *Basic Electronics* has made you familiar. Note carefully that, unlike the sound carrier which may be either amplitude-modulated or frequency-modulated, **the vision carrier is always amplitude-modulated.**

After modulation, the carrier is again amplified many times by a number of powerful amplifiers, so that the radiated signal shall have sufficient strength to meet the range requirements of the transmitter. The signal is then passed through an **impedance matching** stage to a short length of feeder cable. This feeder takes the signal into a circuit called a **sideband filter,** whose object is to limit the frequency bandwidth required by the radiated signal.

The vision signal (less most of one of its sidebands) is then combined with the sound signal (complete with both *its* sidebands) in a **combining unit;** and the two signals are fed to the aerial through special low-loss transmission lines. From the aerial the two signals are radiated in the form of electromagnetic waves.

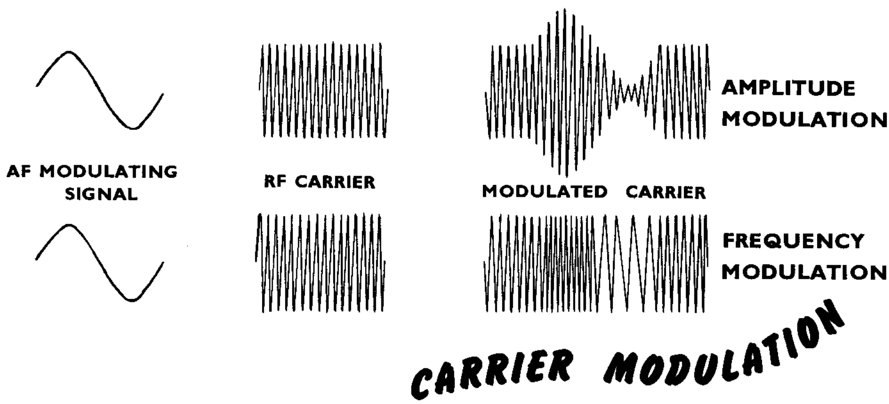
Up to the time when it emerges from the Power Amplifier stage, the vision signal is handled in much the same way (in principle) as is the amplitude-modulated sound signal. It will be convenient to break off for a moment, therefore, and have a look at how the TV sound transmitter works.

The TV Sound Transmitter

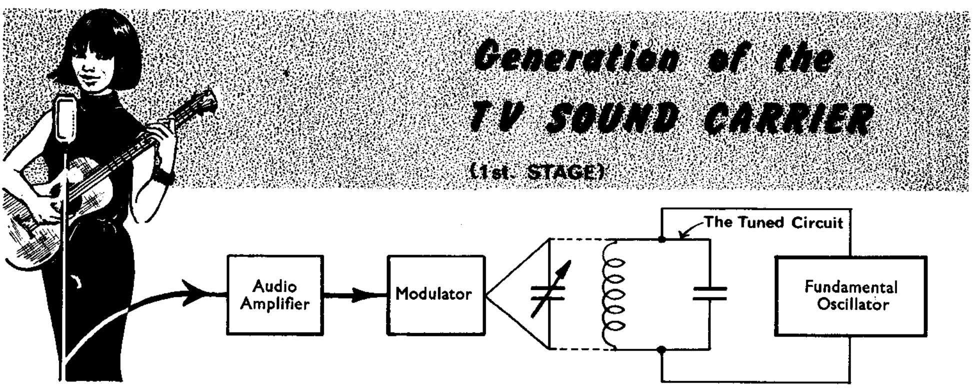
The television sound transmitter is in principle like any other transmitter used for the transmission of sound signals. Indeed, radio and TV sound transmitters of the BBC have often been used in conjunction with one another for the transmission of experimental stereophonic programmes.

TV sound transmitters, like their radio counterparts, are of two main types—those in which the *amplitude* of the carrier is modulated, and those in which its *frequency* is modulated. The present British 405-line TV system employs amplitude modulation for the sound carrier, as do the French 819 and 625-line systems. Countries using the CCIR-recommended 625-line system, however, use frequency modulation of the sound carrier; and it is this type of modulation which is used in the British 625-line system (BBC 2).

Frequency modulation, as you know, differs from amplitude modulation in that the FM carrier is maintained at constant amplitude while its frequency is altered by amounts which vary with the amplitude of the modulating signal. In amplitude modulation it is the other way about—the frequency remaining steady while the amplitude varies with the signal. The waveforms below show what an r.f. carrier looks like when it is modulated by either method.

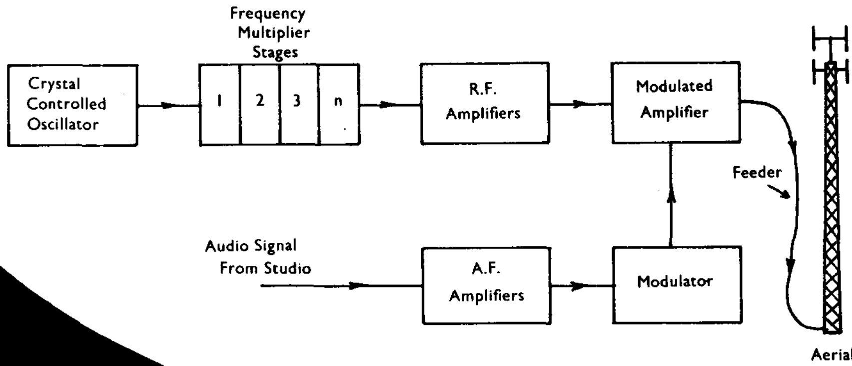


The first stage in the generation of the sound carrier, as it is of the vision carrier, is an oscillator circuit (usually crystal-controlled) operating at a fundamental frequency considerably lower than that of the carrier which is eventually to be radiated. The carrier produced by this oscillator is fed to a modulator stage, where it is mixed with the sound signal.



The TV Sound Transmitter (*Continued*)

You learnt in Part 4 of *Basic Electronics* how **amplitude modulation** of the carrier wave is effected. Here is a diagram to remind you of the process.



The AMPLITUDE-MODULATED Transmitter

Oscillators tend to be more stable at low frequencies in the VHF range, so a crystal oscillator with a frequency of 5 MHz might be used to provide the fundamental frequency for a 50 MHz carrier. It would be brought up to the required frequency by being passed through a number of frequency-multiplier stages.

The carrier is then amplified (in the *R.F. Amplifiers* block in the diagram above) until it is strong enough to drive the power amplifier in the next stage.

The audio signal will seldom come in from the studio with an amplitude of more than about one volt. It must therefore be put through a number of a.f. amplifier stages before it can be applied to the modulator.

As you learnt in *Basic Electronics* (pages 4.79 onwards), the modulating signal can be applied either to the anode or to the grid of the final power amplifier of the transmitter. In either case, PA output current (and so the amplitude of the carrier) is varied in precise ratio to variations in the amplitude of the audio signal.

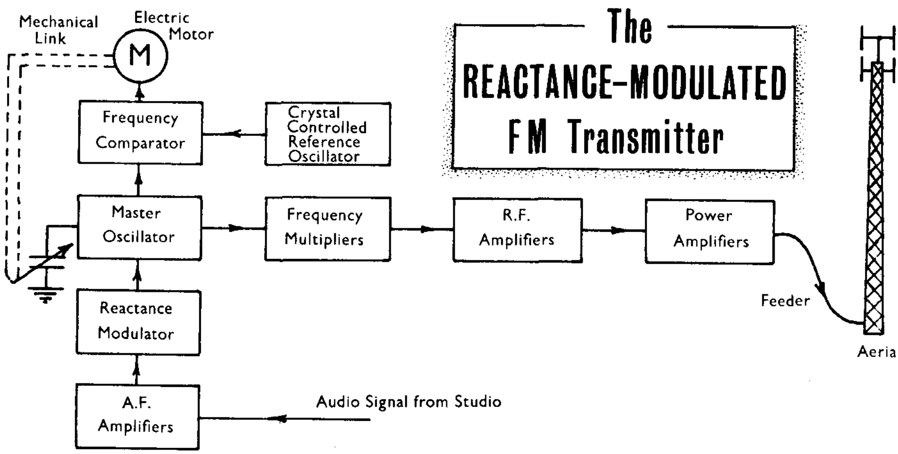
The final amplifying stage, when modulated in this way, is known as the *modulated amplifier*. Besides combining the audio signal and the carrier, the stage produces most of the power required to radiate the signal from the aerial.

In some systems, modulation of the carrier is performed at an earlier stage in the transmitter, and the signal is amplified to its final strength only after modulation. Such a process is called *low-level modulation*, as opposed to the *high-level modulation* technique described above.

The TV Sound Transmitter—Frequency Modulation, Direct Type

Frequency modulation of the carrier wave was explained in Part 6 of *Basic Electronics*. There are two main methods, both of which are currently used in transmitters of the BBC. The first, the *direct type of frequency modulation*, employs an LC oscillator whose frequency is directly modulated by a *reactance modulator*. The advantage of this method is that frequency-modulation of the carrier is easily achieved. Its main disadvantage is that the stability of the mean frequency of the oscillator is often poor, so that a special frequency-stabilizing stage has to be added to the circuit (see next page).

The block schematic of the reactance-modulated, direct-type FM transmitter which follows should be studied in conjunction with the more detailed explanation of its working given in *Basic Electronics*, Part 6.



Briefly, what happens is this. The audio signal received from the studio is amplified, and then fed to a reactance modulator stage whose function is to modulate the frequency of the master oscillator in direct proportion to the amplitude of the audio signal.

The **reactance modulator** is a circuit which is made to behave in a manner very like a variable capacitor. It is connected to the fundamental oscillator in such a way that its effective capacitance is placed in parallel with (and therefore forms part of) the tuned circuit of the oscillator. In the absence of a signal input, the effective capacitance of the modulator is steady; but when a signal is applied, the capacitance varies by amounts which depend on the amplitude of the signal input—large amplitude signals causing much greater changes in effective capacitance than signals of lesser amplitude.

You know that the frequency of an LC oscillator is governed by a formula in which the variables are the total inductance and the total capacitance in its tuned circuit $\left(f = \frac{1}{2\pi\sqrt{LC}}\right)$. So the frequency of the master oscillator must vary every time an audio signal applied to the reactance modulator changes the effective capacitance in the oscillator tuned circuit—and it must vary by an amount which is directly proportional to the changing amplitude of the audio signal.

The amount of this variation is called the *frequency deviation*.

The TV Sound Transmitter—Frequency Modulation, Direct Type (*continued*)

From the fundamental oscillator, the now-modulated carrier passes to a number of **frequency multiplier** circuits like those used in the vision transmitter. These circuits not only multiply the fundamental frequency itself, but also (and in exactly the same proportion) the deviations in its frequency caused by the audio modulations.

Take, for instance, an oscillator operating at 5 MHz and having a maximum frequency deviation (corresponding to the maximum amplitude of the modulating signal) of 3·75 kc/s. If the final operating frequency of the transmitter is to be **100 MHz,** the frequency-multiplier circuits must clearly step up the carrier frequency by a factor of 20. This exact multiplier will also be applied to all the deviation frequencies, and will step up the maximum deviation to 20 times 3·75, or **75 kHz.**

Later stages of the transmitter increase the power of the modulated carrier to a level high enough to meet its range and signal-strength requirements. Typical power outputs actually radiated from the aerial vary from about 3 kilowatts, up to 120 kW for the longer intended ranges.

Control of the rather unstable mean frequency of the master oscillator in the frequency-modulation (direct type) circuit can be achieved in more than one way. One such method was described in Part 6 of *Basic Electronics.* Here is another.

Part of the output signal from the master oscillator is fed to a *frequency-comparator* circuit (see block diagram on preceding page). This circuit compares the frequency of the master oscillator signal to the frequency of a very stable crystal-controlled reference oscillator. If the frequency of the master oscillator differs from that of the reference oscillator, a difference-frequency (or *beat-frequency*) signal is produced.

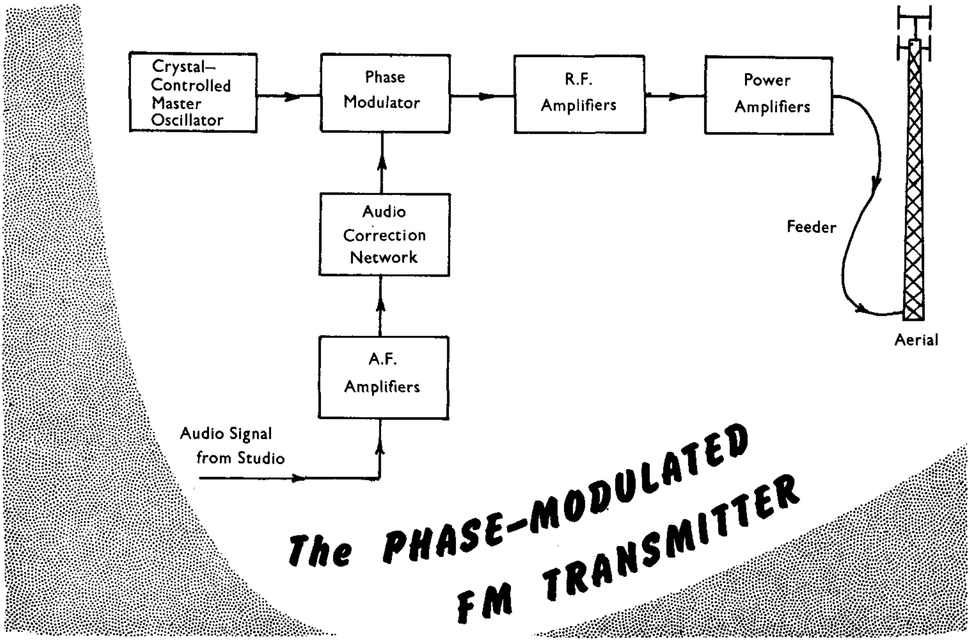
The comparator uses this signal to produce a controlling voltage for a small servo motor. The greater the difference in the frequencies of the two oscillators, the greater will be the amplitude of the controlling signal.

The shaft of the servo motor is mechanically linked to the shaft of a variable capacitor which forms part of the tuned circuit of the master oscillator. If the frequency of the master oscillator is *higher* than it should be, the polarity of the controlling signal will be such that the motor is turned in a direction which will *increase* the value of the variable capacitor. From the frequency formula, you know that this will cause a *reduction* in the frequency of the master oscillator.

Conversely, if the frequency of the master oscillator is *lower* than it should be, the polarity of the beat-frequency control signal will be such as to turn the servo motor in the opposite direction. The value of the variable capacitor in the tuned circuit of the master oscillator will be *reduced*; and the effect of introducing a carefully measured lower value for C into the equation will be that the frequency of the master oscillator is *increased* by the amount needed to bring the two oscillator frequencies back into balance.

The TV Sound Transmitter—Frequency Modulation, Indirect Type

The second currently-used method of frequency modulation is the *indirect type.* It employs a crystal-controlled master oscillator having excellent frequency stability, the output of which is (with more difficulty than in the direct type) frequency-modulated at a later stage. Here is a block diagram of the circuit arrangement.



No controlling device is needed by a crystal oscillator save for a thermostatic arrangement to keep the crystal itself at a constant temperature.

Modulation of the carrier is achieved in the next stage, by means which you studied on page 6.18 of *Basic Electronics.* You there learnt that when a constant-frequency r.f. signal is applied to a network consisting of either a capacitive or an inductive reactance in series with a potentiometer, the phase of the output signal can be shifted by varying the resistance. Substitute a triode or transistor for the potentiometer and apply the audio signal to its grid (or to its base or emitter as the case may be), and the constant frequency of the oscillator signal will be shifted in phase in proportion to changes in the amplitude of the audio signal, and at a rate dependent on its frequency.

After modulation in this way, the carrier is passed through a normal series of r.f. and power amplifiers on its way to the aerial.

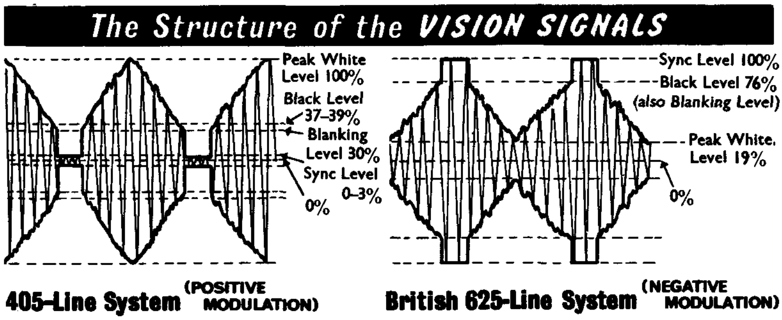
The need for the *audio correction* network shown in the diagram between the a.f. amplifiers and the phase modulator was explained on *Basic Electronics,* page 6.19. The tendency in the phase-modulated FM transmitter is for the amount of frequency deviation in the modulated carrier to increase in proportion, not only to the *amplitude* of the audio signal but also to its *frequency*—with appreciable distortion of the modulation of the carrier arising in consequence.

The basic method of eliminating this danger is to decrease the amplitude of the audio signal in proportion to any rise in its frequency, by passing the signal through a simple RC voltage-divider network of the type described and illustrated on the page quoted.

The TV Vision Transmitter—Impedance Matching

You last left the vision signal, you remember, some five pages back when it was emerging from the Power Amplifier stage. The illustration shows the shape of the signal at this point, in both the 405-line and 625-line systems.

Also shown on the illustration are the relative amplitudes of the various signal levels which you studied when you were reading about the picture-sync ratio on page 1.76.



The vision signal is now a very powerful one, and the physical difficulties of handling it are considerable.

A typical PA stage, for example, may consist of a pair of triodes connected either in "push-pull" or in parallel. The voltage supplied to the anodes of these valves may well be of the order of 6000 volts, and very large currents are thereby caused to flow. The heat generated in the triodes by the resulting high power dissipation ($P = V \times I$) is great enough to call for measures of forced cooling. Some types of PA valve are partially encased in water-jackets and are cooled by re-circulated water, as in the engine of your car. Others are cooled by an air blast, the resulting warm air being sometimes used to heat the transmitter building.

When it leaves the PA, the vision signal passes through an impedance-matching stage, the purpose of which you will understand if you look back at §5 of *Basic Electronics*, Part 4. You there learnt that, if maximum transfer of power is to be achieved from a transmitter through a feeder to an aerial, and then radiated by that aerial, it is important that the output impedance of the transmitter, the characteristic impedance (Z_0) of the feeder, and the input impedance of the aerial should all be closely matched.

Now the output impedance of the vision transmitter ("looking back into it", as it were) is typically not less than 4000 ohms. The input impedance of a dipole aerial, as you will learn later in this Section, is affected by a number of factors, but is always very much lower—typically of the order of 50–80 Ω. Feeders can be manufactured with widely varying characteristic impedances; but those with a Z_0 of around 50 to 80 ohms have considerable practical advantages.

It is therefore common practice to pass the vision signal through an impedance-matching stage capable of lowering the Z to a value of around 50–80 Ω. The signal is then taken to the aerial along a feeder with a Z_0 of that approximate value.

At the lower VHF frequencies, impedance-matching is carried out easily enough with the aid of a transformer whose secondary is tapped in such a way that the number of turns in it can be varied at will.

Impedance Matching (*continued*)

The impedance of the primary of a transformer (Z_p) is related to the impedance of its secondary (Z_s) by the expression:- $Z_p = N^2Z_s$, where N is the turns ratio of the transformer.

Thus in order to match a transmitter impedence of 4000 Ω into a feeder impedance of 75 Ω, the turns ratio of the matching transformer would need to be calculated as follows:

$$N = \sqrt{\frac{Z_p}{Z_s}} = \sqrt{\frac{4000}{75}} = \sqrt{53} = \text{about } 7{\cdot}3\,.$$

Thus the matching transformer should have a turns ratio of about 7·3:1 in order to achieve the desired impedance match. Note, though, that in order to handle the power and high voltages involved in a big TV transmitter, the matching transformer will need to be a very sizeable affair.

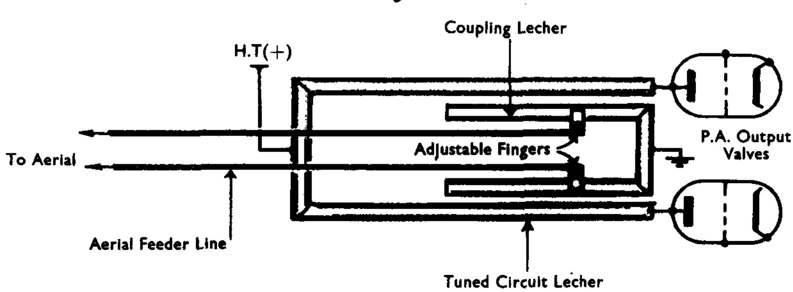
At UHF, the ordinary type of transformer cannot be used—because (for one reason) capacitive losses between the windings become too high. It is therefore usual for the output of the transmitter to be coupled to the feeder by means of specially-made lengths of transmission line called **lecher lines.**

Lecher lines are hollow metal tubes, typically between 10 and 20 millimetres in diameter, whose surfaces are silver-plated in order to minimize resistance to current flow at very high frequencies. (You will learn more about this in Part 2, when you meet a phenomenon called *skin effect* in the UHF receiver.)

A lecher (pronounced *lekka*) line of appropriate length is similar to a quarter-wave stub, except that it is of better quality so as to keep power losses at very high frequencies to a minimum. When one such line is placed close to another one, which itself forms part of a tuned circuit, a voltage is induced in the second line by normal transformer action. If this second, or coupling, lecher is made exactly a quarter of a wavelength long and is shorted at one end, its impedance will vary from zero at the shorted end to a very high value at the open end.

Somewhere along the length of the coupling lecher there will therefore exist a value of impedance suitable for matching into the feeder. Adjustable "fingers" connected to the two conductors of the feeder are moved along the length of the coupling lecher until the desired Z is found.

IMPEDANCE MATCHING by LECHER LINE



Note that lecher lines are used at the higher VHF frequencies in Band 3, as well as at UHF. It is simply a matter of which works best—lecher line or transformer.

The Sideband Filter

You will remember from what you learnt in Part 4 of *Basic Electronics* that whenever a low-frequency signal is used to modulate the amplitude of a high-frequency carrier, two additional frequencies are produced which are called **sidebands.** These two frequencies lie respectively above and below the frequency of the carrier; and are distant from that frequency by equal amounts.

The amount of this divergence from the carrier frequency depends on the frequency of the modulating signal. When, for example, a 200 kHz carrier is modulated by a 5 kHz signal, one sideband frequency (known as the *upper sideband*) will be 5 kHz above the carrier, and the other (the *lower sideband*) will be 5 kHz below it.

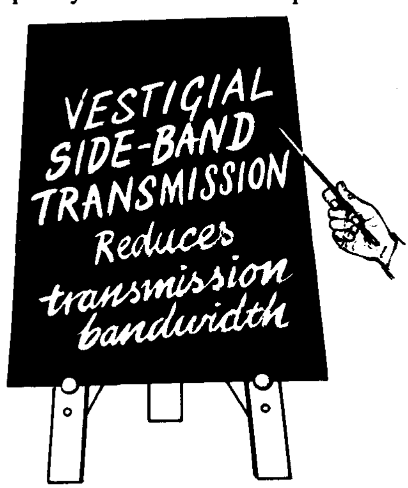
There are, therefore, three separate frequencies present in the modulated carrier—the carrier frequency itself of 200 kHz; the upper sideband frequency of 205 kHz; and the lower sideband frequency of 195 kHz. Note that the two sidebands are separated from one another by *double the frequency of the modulating signal.*

You know that the highest and lowest frequencies present in the modulated carrier are those corresponding to the highest and lowest frequencies present in the modulating signal. If, then, the intelligence contained in the transmitted carrier is to be faithfully reproduced at the receiver, the bandwidth of the receiver must be sufficiently wide to accept the full range of frequencies produced during modulation.

There is no great problem with the comparatively low-frequency signal which is used to modulate the sound carrier; for doubling the frequency of this signal produces no very wide *total* bandwidth. But with the much-higher-frequency signal used to modulate the *vision* carrier, the two sideband frequencies produced are much farther apart. In the 405-line system, both frequencies extend to at least 2·5 MHz—which means that if the full range of modulation frequencies are to be transmitted, the total bandwidth required for satisfactory reception will be at least twice 2·5 MHz.

Add to this total vision-carrier bandwidth of not less than 5 MHz the full bandwidth required by the modulated *sound* carrier, and you get an overall transmission bandwidth which is very high. The original London TV transmitter at Alexandra Palace, indeed, used to transmit a vision carrier of 45 MHz, plus both its sidebands. Overall width of the vision carrier was therefore the wide one of 45 ± 5 MHz.

Double-sideband transmission on the vision carrier clearly restricts the number of channels which can be fitted into a given frequency band. A technique has been worked out, however, which allows *the greater part of either one* of the sidebands to be suppressed without impairing the quality of the picture reproduced at the receiver—provided that the receiver has been appropriately designed. The overall bandwidth required by the modulated vision carrier is in this way much reduced.



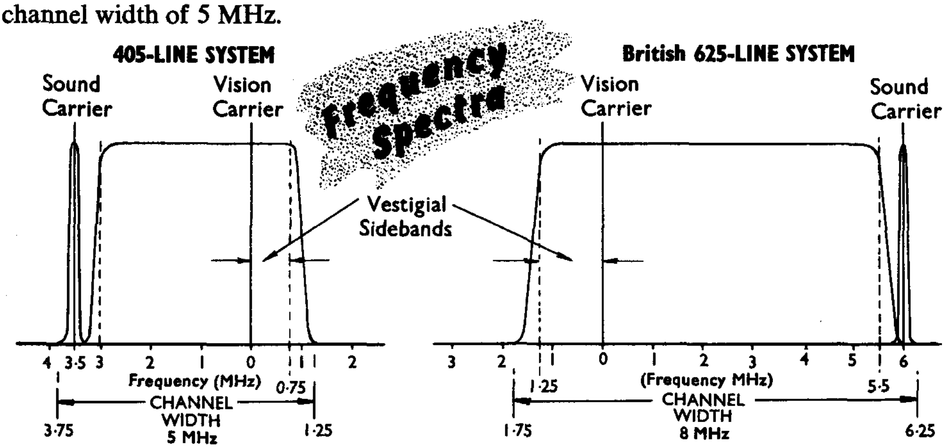
This type of transmission is now used by TV systems all over the world. It is known as **vestigial sideband transmission,** by reason of the fact that only a "vestige" of one of the two side-bands is transmitted.

The Side-band Filter (*continued*)

The suppression of one of the two vision sidebands is carried out at the transmitter. It is done in one of two ways—either by deliberate mistuning of certain tuned circuits, or by the insertion of a **sideband filter** circuit in which one sideband is filtered off and caused to dissipate its power in an absorber resistance. Filters are usually lengths of concentric cable connected across the signal feeder and terminated in the resistance.

In the 405-line system it is the *upper* sideband which is restricted, the *lower* sideband being transmitted in full. The diagram below shows (on the left) how the sound and vision carriers are situated in the frequency spectrum, and where the sideband is is reduced. Note that the upper sideband of the vision carrier is transmitted in full up to 0·75 MHz, but rapidly attenuated thereafter until it is completely suppressed at 1·25 MHz. The lower sideband, on the other hand, is transmitted at full amplititude for approximately 3 MHz, and then reduced to zero so as not to interfere with the sound carrier being radiated at 3·5 MHz below the vision carrier. The two sidebands associated with this sound carrier are so small (less than 20 kHz each) that they cannot be shown on the diagram without exaggerating them right out of scale.

You will see that the upper and lower extremities of the channel are plus 1·25 MHz and minus 3·75 MHz relative to the frequency of the carrier, thus making an overall channel width of 5 MHz.



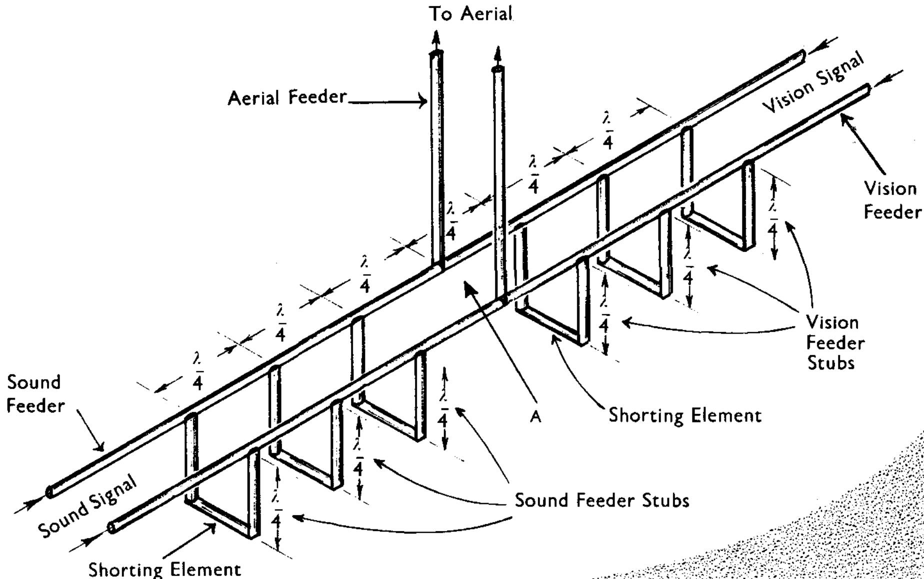
The technique of vestigial sideband transmission is also used in the British 625-line system; but there are nevertheless important technical differences between the two systems. The principal ways in which the 625-line system differs from the 405-line system can be summarized (in so far as their respective frequency spectra are concerned) as follows:

1. In the 625-line system, it is the *lower* sideband which is suppressed, not the upper.
2. The overall channel width is 8 MHz, instead of 5 MHz.
3. Within this overall channel width, the width of the unsuppressed vision sideband is 5·5 MHz, instead of 3 MHz.
4. The vestigial sideband is restricted to 1·25 MHz, not to 0·75 MHz.
5. The sound carrier is radiated at a frequency 6 MHz *above* the vision carrier, instead of 3·5 MHz below it.

Combining the Sound and Vision Signals

The job of the combining unit is to feed the separate sound and vision signals into a common output feeder line in such a way that there is no risk of the vision signal getting back down the line into the sound transmitter or of the sound signal getting back down the line into the vision transmitter.

There are several ways of combining the outputs of the two transmitters without this danger developing, one of the simplest being that shown in the diagram below.



The COMBINING UNIT

The outputs from the two transmitters are joined at Point A. At intervals equal to one-quarter of the wavelengths of the respective signals back along each line from this point, there are connected a number of pairs of quarter-wave ($\lambda/4$) short-circuited stubs. You learnt about stubs of this kind on page 4.55 in *Basic Electronics*. In the diagram above, they are the vertical elements connected to the twin wires of the two feeders. Each stub is "shorted" by a horizontal element joining it to the end remote from the feeder of its stub pair.

These stubs resonate at one frequency only—that at which the physical length of the stub corresponds to one-quarter of the wavelength of the signal. If, then, the lengths of the stubs on the sound and vision feeders are made exactly one-quarter of the wavelengths of the sound and vision signals respectively, these signals will encounter a very high impedance "looking into" every stub in turn and will therefore pass on their way to the common feeder unimpaired.

But when a signal whose frequency differs significantly from the frequency to which a stub is resonant is applied across the stub, the impedance of that stub will drop; and the more the frequency of the applied signal differs from the stub's resonant frequency, the lower will this impedance fall. If the frequency difference is great enough, the impedance will fall to a very low value, and the stub will act virtually as a short-circuit.

Combining the Sound and Vision Signals (*continued*)

You know that the frequencies of the sound and vision signals in a TV transmission always lie some MHz apart. Thus when a signal tries to intrude down the wrong feeder—say, for example, the vision signal down the sound line—it inevitably has a frequency different from that to which the stubs on the forbidden feeder are designed to resonate. The first stub encountered will therefore offer to the intruding signal a very low impedance. The signal will flow down the stub; and much of its energy will be dissipated in the virtual "short" which it offers to the signal.

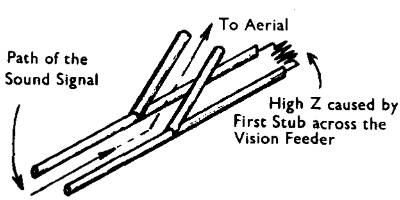
Moreover, you also know that a low impedance at one point across a line is automatically reflected as a very high impedance across the same line one-quarter of a wavelength back along it. Since the stubs are carefully spaced at quarter-wave intervals from Point A (in the illustration on the last page) the intruding signal, on meeting the first low-impedance stub, automatically sets up a very high impedance to any signal of its own frequency across the feeder back at Point A.

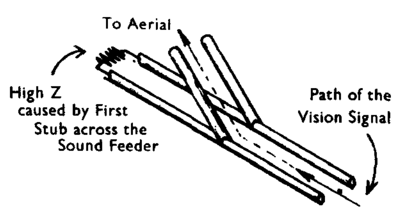
It is rather like a band of escapers from a prison castle groping their way along a secret tunnel, but each unconsciously setting off a trip-wire which progressively closes the door into the tunnel every time it is tripped. Thus every extra man entering the tunnel makes it harder for a companion to follow him through the steadily narrowing entrance.

The reduced current getting past the first stub flows on up the forbidden feeder until it encounters the second stub—whereupon an identical process of "tripwire" and "trapdoor" is repeated, with the very high impedance at Point A now reinforced by a second high impedance set up across the line at the first stub by the action of the "tripwire" at Stub 2.

Both the sound and (especially) the vision signals have been raised to very considerable power by their passage through the Power Amplifier stage. So a succession of stubs (seldom less than three) may be needed before the last of the energy of an intruding signal is dissipated in the virtual "short" offered by the last stub to which it manages to struggle through the successive barriers set up in the line against it.

Meanwhile, back at Point A the common feeder to the aerial, which has no "signal-trapping" stubs attached to it, offers a path of very low impedance to sound and vision signal alike. Both therefore prefer to take this easy path rather than try to force their way along the feeder respectively forbidden to each.

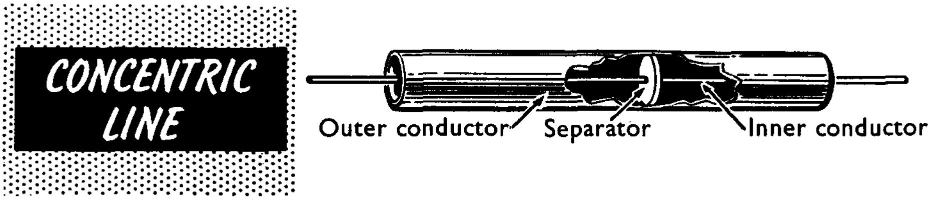




The feeders in the diagram of the combining unit on the preceding page were shown as being of the open-wire type—largely for convenience of illustration. But the same principle can be applied with feeders of the concentric type. The stubs then consist of $\lambda/4$ lengths of cable connected across the feeder, while across the other end of the stub the two conducting elements of the concentric cable are connected together to form the short-circuit required.

Aerial Feeders

You learnt a good deal about transmission lines, or feeders, in Part 4 of *Basic Electronics*. The type of feeder most commonly used in TV transmitting stations is a semi-flexible concentric cable similar to that described and illustrated on page 4.57 of that Series.



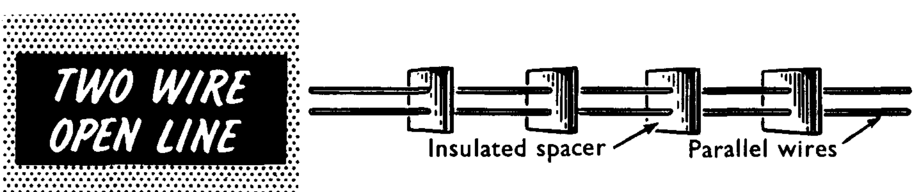
The diameter of the cable will range from about an inch up to six inches or so, normally increasing in proportion to the amount of power which the feeder is required to carry. The thicker types of cable would be used to feed the higher-powered transmitters radiating from a hundred kilowatts up to as much as 1000 kW of power.

A particular advantage of the concentric type of cable is that its cylindrical outer conductor can be earthed in order to screen the inner conductor against electrical losses caused by radiation from the line itself. This is an important consideration, for the distance between transmitter and aerial is seldom less than 1000 feet (or well over 300 yards). Electrical loss from a cable of that length could dissipate an important fraction of the power being transmitted to the aerial, if screening was less than adequate.

Another possible source of electrical loss is the accumulation of moisture caused by condensation in the dielectric spacing between the two conductors. At worst, this could cause a full short-circuit between the two. Some feeders have warm air ducted under pressure through them (*i.e.*, between the two conductors), in order to counteract this danger.

Transmission lines of this type can be constructed with varying characteristic impedances, generally somewhere between 50 and 150 ohms, depending on the input impedance of the aerial. This impedance, as you will see, depends on a number of factors; but, whatever its value, it is normally the impedance of the aerial which determines the Z_0 specified for the transmission line, and therefore the impedance to which the matching unit must lower the output impedance of the transmitter itself.

Feeders with a characteristic impedance much higher than the 50–150 Ω range mentioned above can be built, and are still in use in some of the earlier transmitting stations; but they need to be of the open two-wire type pictured on *Basic Electronics*, page 4.57.



Feeders of this type, however, possess the disadvantage of being unscreened. They therefore tend to lose power by radiation. It is also difficult to maintain the exact spacing of the wires along the line in rough weather, with the result that their impedance fluctuates. Mismatching results, and power loss occurs.

The Aerial

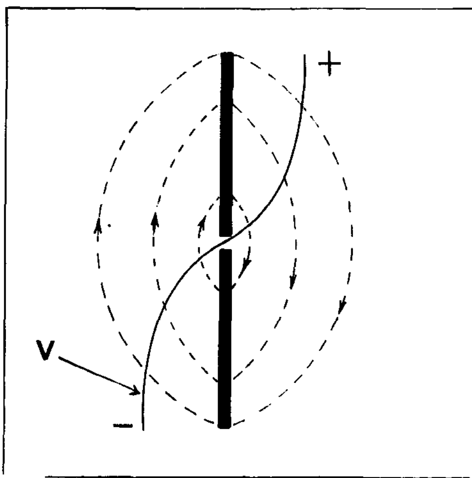
The function of any transmitting aerial—whether it is being used for radio, for television, for radar, or even for trying to bounce back a signal through space from Mars—is to convert the variations in current or voltage of the modulated signal into an electromagnetic wave, and to radiate this wave in the desired direction (or in all directions at once).

You learnt in Part 4 of *Basic Electronics* that a type of aerial much used in transmitters is the *Hertz aerial*, or *half-wave dipole*. The frequencies used in TV are especially suitable for the half-wave dipole, and its employment in TV transmitting stations is general.

Refer back at this point to pages 4.59 to 4.70 of *Basic Electronics*, where the basic principles of how all aerials work are explained. You learnt there, in particular, that a half-wave dipole behaves like a series-resonant tuned circuit. It is as if its two halves were the last bits of an open-ended transmission line bent back at right angles *at a point exactly one-quarter of a wavelength back from the open end.* You also learnt that, when a.c. flows in a half-wave dipole, the voltages at all corresponding points on the two halves of the dipoles are at all times equal in amplitude but opposite in polarity.

There therefore exists between the two halves of the dipole when current is flowing in it an **electric** field, having a direction towards the more positive charge, which is similar in nature to the electric field existing between the plates of a capacitor. When a large current flows in the dipole, this field will be strong.

When the current changes direction, the voltages in the two halves of the dipole change polarity, and the direction of the field changes with them. The field therefore collapses very rapidly, and equally rapidly builds up again in the opposite direction. The general pattern of the field is shown in the illustration below; but remember that the plus and minus signs are constantly changing position so that the direction of the arrows is constantly reversing as the field builds up, collapses, and builds up again with opposite polarity.

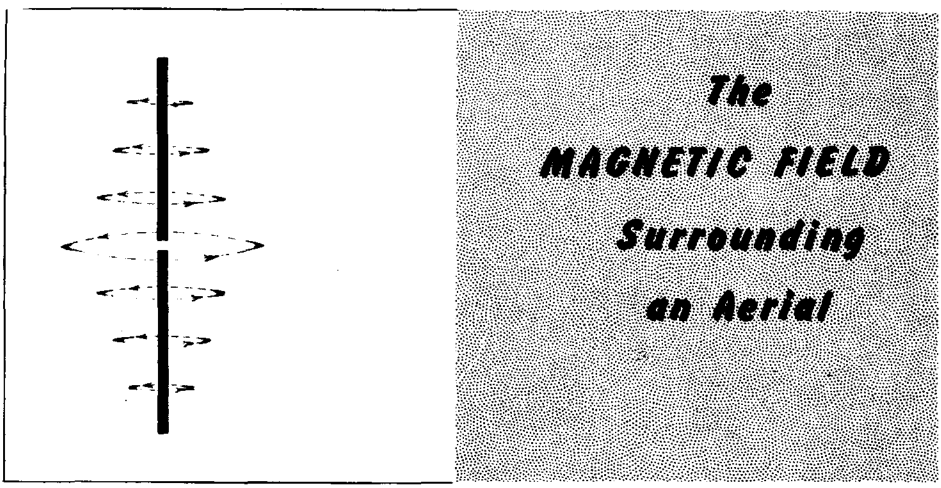


The ELECTRIC FIELD Surrounding an Aerial

Remember that the electric field of a dipole is *capacitive* in nature; and that the plane of the field is the same as that of the two halves of the dipole.

The Aerial (*continued*)

Besides the electric field described on the last page, the a.c. flowing in the dipole gives rise also to the type of **magnetic** field which always builds up round a conductor in which current is flowing. When the current flow in the dipole reverses, this *inductive* field collapses and builds up again rapidly with opposite polarity. Again you have the alternating effect—but this time in a plane at right angles to the direction of current flow, and therefore at right angles to the dipole. The best way to picture it is to imagine that you are poised vertically above the tip of the aerial mast and looking down on it. The magnetic field radiates from the aerial exactly as would ripples if you dropped a stone into a pool of water from this position.



The electric and magnetic fields around the dipole are therefore *at right angles to one another*. They alternate about the dipole aerial—building up to a peak, collapsing and building up to another peak in the opposite direction—at the same frequency as that of the current flowing in the aerial, and varying slightly (in amplitude, in frequency or in both) according to the variations imposed on the carrier by the audio and video modulating signals.

How the Electromagnetic Waves Are Radiated

You have seen that the capacitive-type electric field is caused by voltage differences in the dipole, and the inductive-type magnetic field by variations in the flow of current. You know that current and voltage in a tuned circuit are out of phase with one another. When circuit resistance is low (as it is in a well-designed dipole), they are almost 90° out of phase. Thus the electric and magnetic fields round a dipole expand and collapse out of phase also. When one is at its peak, the other has almost collapsed. It is as if at one moment all the energy fed into the dipole were stored in the capacitances and at the next moment in the inductances. The reinforced alternating effect goes on for as long as a.c. flows in the dipole.

The power delivered to a modern transmitting aerial is very considerable—several hundreds of kilowatts would not be unusual. So the fields generated are strong. As these strong fields repeatedly and rapidly build up and collapse, portions of both escape from the aerial altogether and are radiated into space as electromagnetic waves carrying the transmitted intelligence to distant receivers.

The Half-Wave Dipole

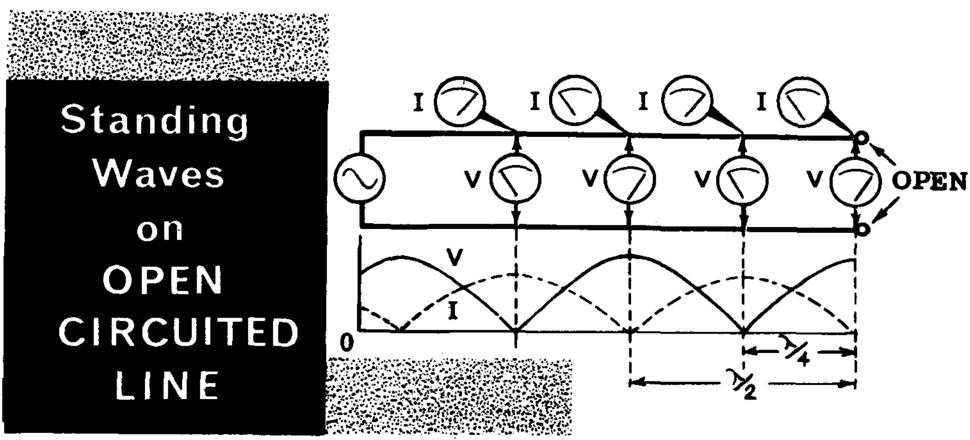
You know from *Basic Electronics*, Part 4, that an effective half-wave dipole is formed when the wires of an open-ended transmission line are bent back at right angles at a point one-quarter of a wavelength back from the open end. With the conductors opened out in this way, the fields surrounding them can be radiated. When they were close-spaced, the fields were mutually cancelled out.

In practice, however, the aerial is seldom formed by bending back the wires of a line. It almost always consists of either a hollow or a flattened rod of the correct electrical length. Such a rod has important advantages over a pair of wires. It possesses rigidity; it stands up better to bad weather; it can handle much more power; and (as you will shortly see) by increasing the diameter of the rod relative to its length, the bandwidth transmitted by the aerial can be usefully broadened.

Nevertheless, the simile of the bent-back transmission line is useful, for it points up some essential facts about any half-wave dipole aerial.

First, the length of each arm of the dipole must be almost exactly one-quarter of the wavelength of the signal which the aerial is designed to radiate (for the "almost", see later). This means that a half-wave dipole of given length can radiate with full efficiency *only* a signal whose wavelength is four times the length of one of the dipole arms (or twice the dipole's own overall length). If you want to radiate a signal having a different frequency (and therefore a different wavelength), you have to use a dipole of different length.

The illustration below will remind you of the reason for this critical quarter-wavelength dimension of each arm of the half-wave dipole. Observe the standing waves of current and voltage which exist at a point one-quarter of a wavelength ($\lambda/4$) back from the open end of the transmission line—*voltage minimum, current maximum.*



Note that the same conditions of maximum current and minimum voltage also occur *three-quarters of a wavelength* back from the open end of the transmission line. If you bent back the line at this point, you would get a dipole with the same properties of an LC tuned circuit resonating to a signal of the same wavelength as before. But its length would be unnecessarily great, and its propagation characteristics different.

You may say, therefore, that the half-wave dipole represents the *shortest* length of aerial in which the conductor arms behave as a tuned circuit resonant at the desired frequency.

The Half-Wave Dipole (*continued*)

The distribution of current and voltage along a half-wave dipole at resonance is now easy to follow. Current was maximum and voltage minimum at the point where the transmission line was notionally bent back to form the aerial. Current will therefore be maximum and voltage minimum at the centre of the dipole, and *vice versa* at its two ends.

If you now apply Ohm's Law, in the form Z = V over I, to the voltage and current at various points along the dipole, you will find that the impedance "looking into" each end of the dipole is very high. Theoretically, it is infinite; for current, having nowhere to go to, cannot flow there. In practice, a little current *does* flow, and the impedance at the ends of a dipole is typically of the order of 3000 ohms.

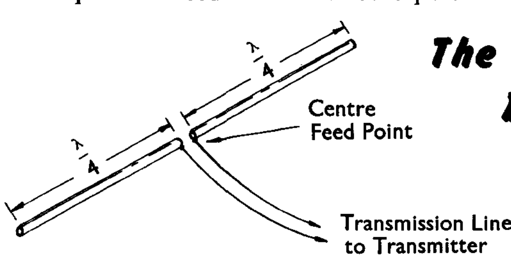
In the centre of the dipole, on the other hand, voltage is theoretically zero, so impedance should be zero also. In practice, most TV transmitter dipoles have a centre impedance of the order of 50 to 80 ohms (though, as you will see later in this Section, there are a number of factors which affect the Z of a dipole in different ways).

You now see the importance of those matching transformers back in the sound and vision transmitters. The output impedance of the transmitters has a value which cannot be altered, and which is typically of the order of 4000 ohms. The job of matching transformers is to see that maximum power is transferred from a generator with an output Z of that order of magnitude into a load having a Z_{IN} of the order of 50–80 ohms.

But, you may say, I know that the *ends* of a dipole have an input impedance of some 3000 ohms. Surely no grave mismatch would occur if the transmitter was connected across the ends of the dipole, using a feeder having a Z_0 of between 3000 and 4000 ohms? Dipoles of this kind are indeed in use (though they are usually fed at one end only and a special form of matching is employed to take the place of the other terminal). The drawback to them is that a feeder with a Z_0 of 3000–4000 ohms needs to be of the unshielded, twin-wire type, with wide spacing between the wires. There are considerable difficulties in maintaining this spacing uniform throughout the length of the feeder, especially in bad weather or in high winds; and there is also a risk that the open wires will themselves start acting as aerials and will so dissipate some of the power they are supposed to be carrying to the aerial.

For this reason, transmitters typically use fully-screened and weatherproof concentric feeders of about 50 to 80 ohms impedance. At the dipole, the central conductor of the feeder is connected to one half of the dipole and the outer conductor to the other half.

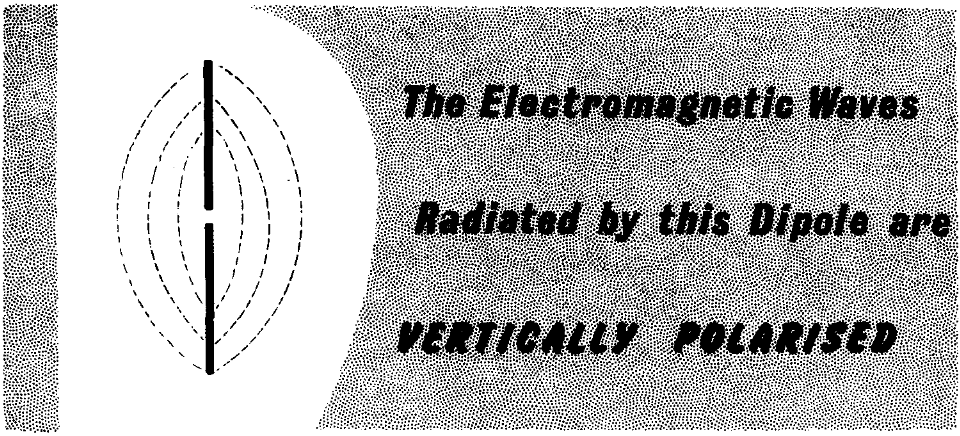
A dipole so fed is described as *current-fed*, because the current flow in the dipole is maximum at the point of feed. An end-fed dipole is said to be *voltage-fed.*



The Half-wave Dipole

The Aerial—Polarization

It is customary to describe an electromagnetic wave by reference to the inclination of its electric field. In the diagram below, this inclination is vertical. The radiated wave is therefore said to be **vertically polarized.**



If the aerial pictured above were to be turned through 90° from the vertical to the horizontal, both fields would likewise move through 90°. The electric field would become horizontal, and the resulting electromagnetic wave would be said to be **horizontally polarized.**

It is usual, in both radio and TV, for the transmitting aerial to be mounted either vertically or horizontally—seldom at any angle between. Radio and TV signals thus normally travel with a polarization either at right angles to the surface of the Earth, or parallel to it.

It is the practice in Great Britain to transmit most (but not all) programmes in the VHF Bands 1–3 with *vertical* polarization. All UHF programmes (save re-transmissions from low-power "fill-in" stations) are to be transmitted with *horizontal* polarization.

The efficiency of a receiving aerial is greatly affected by its positioning with regard to the polarization of the signals to which it is required to respond. *Its efficiency will only be maximum if its orientation corresponds to the polarization of the signal being received.* In other words, an aerial must always be mounted *vertically* for best reception of a vertically-polarized signal, and *horizontally* for best reception of a *horizontally-polarized* signal.

This polarization-sensing property of a receiving aerial can greatly help in preventing mutual interference between two stations transmitting on the same frequency. In Channel 1, for instance, the Crystal Palace (London) transmitter radiates a very powerful signal on 45 MHz for vision and 41·5 MHz for sound. West Cornwall is served by a separate transmitter operating on the same frequencies. Despite the intervening distance, mutual interference would be possible, for reasons which you will see later on; but it is prevented by transmitting the London signal with vertical polarization and the West Cornwall signal with horizontal polarization.

It is for this reason that the familiar "H" and "X"-shaped aerials on which Bands 1 and 2 are commonly received are mounted vertically in and around London; whereas in Cornwall they are mounted horizontally, on a plane parallel to that of the earth.

The Aerial—Dimensions

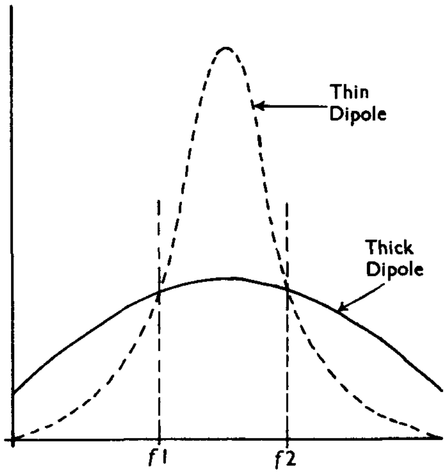
You know that the same television aerial is commonly used to radiate both sound and vision signals, and that the frequencies of these two signals differ by as much as 3·5 MHz in the 405-line system and 6 MHz in the 625-line system. You also know that an aerial cannot radiate a signal of any frequency with full efficiency unless it is resonant to that frequency. How can a single aerial be simultaneously resonant to two frequencies several megacycles apart?

The answer is, of course, that it can't be; and that the frequency to which the transmitting aerial is made to resonate has to be a compromise. The solution is to make the aerial resonant to a *mean* frequency lying between the sound and vision signal frequencies, and to make the response curve flatter and wide enough to embrace both signals.

This can be done by increasing the diameter of the dipole relative to its length. In this way, selectivity is deliberately sacrificed in favour of a response which is adequate at both sound and vision frequencies, but less than optimum for either.

Another drawback of thickening the dipole is that its centre-point impedance may fall low enough to cause added problems of matching.

RESPONSE CURVES of the THIN and THICK DIPOLES



The compromise frequency normally chosen is the geometric mean between the vision signal frequency (call it $\mathbf{f_1}$) and the sound frequency ($\mathbf{f_2}$). The frequency to which the aerial is tuned ($\mathbf{f_r}$) is thus calculated by the equation: $\mathbf{f_r} = \sqrt{\mathbf{f_1} \times \mathbf{f_2}}$.

Take as an example the aerial used for radiating BBC 1 signals from the transmitter at the Crystal Palace.

The frequency of the vision signal radiated by this aerial is 45 MHz, and that of the sound signal 41·5 MHz. The aerial must therefore have a frequency response which is nearly flat over the 3·5 MHz which separate the two signals, so that its efficiency may be approximately the same for both. What "wavelength" is to be taken, in these conditions, for calculating the proper length of the dipole?

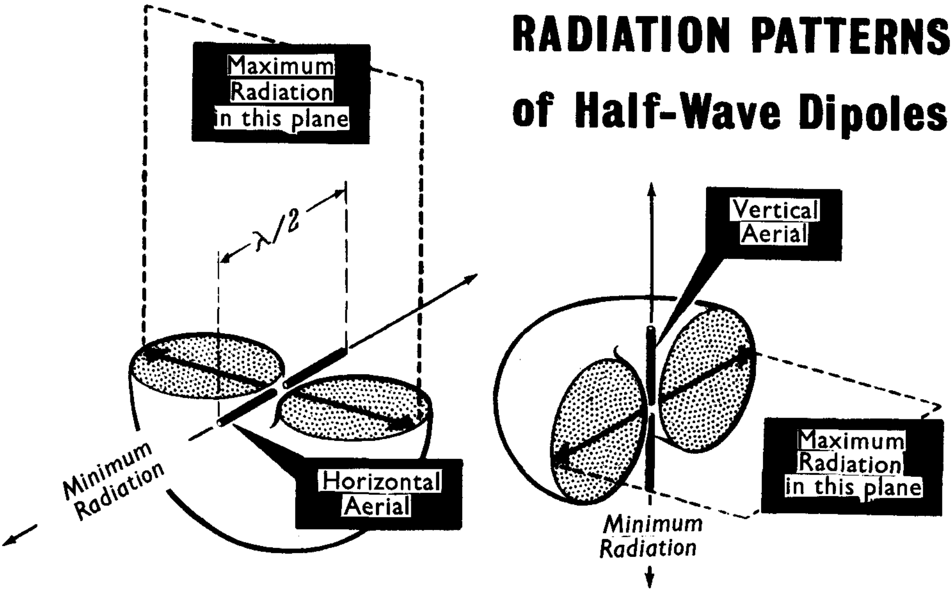
The geometric mean of the frequencies 41·5 MHz and 45 MHz is $\sqrt{41.5 \times 45}$, which works out at about 43·21 MHz. The wavelength corresponding to this frequency is $\frac{3 \times 10^8}{43.21 \times 10^6}$ (see *Basic Electronics*, page 4·45), or about 7 metres. Taking half this wavelength, the theoretical length of the dipole should therefore be about 3·5 metres. But because signals of all frequencies travel somewhat slower through the metal of which a dipole is composed than they do through space, the physical length of a practical dipole is always made slightly shorter than that which would be indicated by theoretical calculation (so that a "half-wave dipole" is in practice more like a "0·48λ dipole").

The Aerial—Directivity

When an aerial radiates electromagnetic waves, the radiation will always be stronger in some directions than in others. Aerials are said to be *directional* along their lines of strongest radiation. In the case of the half-wave dipole, maximum radiation occurs in the plane at right angles to the dipole passing through the point in it at which maximum current flows—*i.e.*, through its centre.

Radiation patterns for half-wave dipoles mounted horizontally and vertically are illustrated below. Both aerials are shown, theoretically, as being mounted in free space. In practice they will be mounted close enough to the ground for their radiation patterns to be appreciably distorted from the ideal patterns shown.

RADIATION PATTERNS of Half-Wave Dipoles



You will see from this diagram that the directivity of the vertical dipole aerial is predominantly horizontal—and the directivity of the horizontal dipole predominantly vertical. This is because of the shape of their respective polar diagrams. (The **polar diagram** of a transmitting aerial may be thought of as a contour line of equal field strength (*see page 1.124*), all round the aerial, showing the *relative effectiveness of transmission* in all directions from it.)

The reason why the polar diagrams are of this shape lies in the distribution of current flow along the dipole. Very little current flows at either end of the dipole, so very little radiation occurs from these ends and minimum signal is transmitted out along the line of the axis of the dipole. Maximum current, on the other hand, flows near the centre of the dipole, and maximum signal will be observed radiating in all directions from this point by an observer "looking into" the centre of the dipole from any position at right angles to its axis.

Note that the horizontal directivity of an aerial system (in other words, its ability to maximize signal strength in a given horizontal direction) can be increased by stacking two or more radiating dipoles one above the other. The effect is to flatten the horizontal radiation pattern and to concentrate more of the radiated energy at the bottom of the beam.

The Aerial—Directivity *(continued)*

When it is desired to concentrate the radiated signal in a particular direction (*e.g.*, predominantly North, as with the BBC and ITA transmitters in the Isle of Wight), special elements called **reflectors** and **directors** are placed behind and in front of every dipole. These greatly reduce radiation behind the dipoles and substantially increase radiation in front of them. You will learn more about reflectors and directors in the Section on receiving aerials in Part 2.

Note, however, that the presence of reflectors and directors reduces the input Z of the dipoles. It is therefore another of the factors affecting the compromise which is always involved when the output impedances of the sound and vision transmitters have to be matched to the Z of the aerial.

The Aerial—Service Area

The **service area** of a TV transmitting station is the geographical area over which reception of its radiated signal is possible. Given a "non-directional" transmitting aerial (that is, one which radiates at equal strength in all directions), the service area viewed from above is theoretically circular; and if it were not for hills, tall buildings and other obstructions would extend to the same limits in all directions.

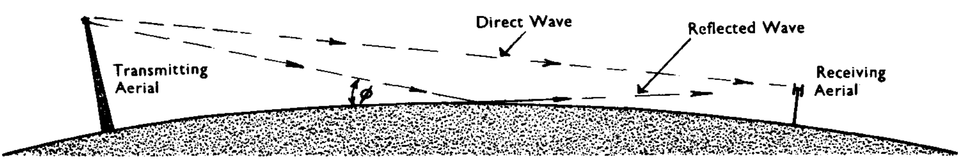
The radius of this theoretical circle is some 60 km (over 35 miles) in all directions from the aerial, with reception beyond this range generally unpredictable. The effective range of a TV broadcast is thus much less than that of the normal radio transmission. The reason lies in the much higher frequency of the TV sound and vision signals.

Recall what you learnt about the theory of wave propagation on pages 4.67 onwards of *Basic Electronics*, and look in particular at the explanation of the frequency spectrum on page 4.70. You will see that at TV frequencies (the lowest used in Britain is the 41·5 MHz available for the sound signal in Channel 1 of Band 1) neither ground waves nor sky waves are effectively usable, and that reliance must be placed on *space-wave transmission.*

At VHF, and still more at UHF, radio waves travel in a virtually straight line; so that the maximum distance over which a signal can be radiated is theoretically limited by the curvature of the Earth to the furthermost points, in all directions, which could be seen from the top of the aerial by the keenest of eyes in perfect weather. The position of these points relative to the aerial form its **optical horizon**; and the radiation of signals from the aerial to this optical horizon is called **line-of-sight transmission.**

TV aerials are almost invariably set up on high ground in order to increase their optical horizon. This gives rise to another kind of wave which reaches the receiving aerial by a slightly different route. Thus at TV frequencies the electromagnetic wave at the receiving aerial is made up of two components. The *direct wave* (or space wave proper) travels from the transmitting aerial straight to the receiving aerial. The *reflected wave* strikes the ground between the two aerials and is bounced off it on its way.

The DIRECT and REFLECTED waves in Line-of-Sight Transmission



The Aerial—Service Area *(continued)*

You will gather from the illustration on the last page that the main factors governing the usefulness of the direct wave are the curvature of the Earth's surface, and the height of the transmitting aerial (and, to a lesser extent, of the receiving aerial) above ground. The relative strength of the reflected wave depends primarily on the angle of incidence (Φ in the illustration) which the wave makes with the surface of the Earth, on the nature of that surface at the point of reflection, and on the polarization of the wave itself.

Remember that you are still assuming that the terrain of the service area is flat. If that assumption does not hold good (and it seldom does), steep hills, large buildings and extensive sheets of water tend to deflect and distort the reflected wave. You will learn more about the effects of these distorting factors in Part 2; but for the moment go on assuming that the service area terrain is flat and normally reflective, and consider the theoretical factors which govern the strength of the transmitted signal at differing points within the service area.

Field Strength

The strength of the transmitted signal at any given point within the service area is known as the **field strength** at that point. It is expressed in either millivolts-per-metre (mV/m) or microvolts-per-metre (μV/m), this being the measure of the voltage induced by the signal in an aerial per metre of its effective electrical length.

The first factor affecting field strength at a given point in the service area is the amount of power transmitted by the aerial. The higher the transmitted power, the greater (other things being equal) will obviously be the field strength at a given point in the service area. The rule is:

Field Strength Varies as the Square Root of the Power of the Radiated Signal

Thus the power of the transmitter would need to be increased by a factor of 16 to achieve a fourfold gain in field strength.

The second factor affecting field strength is the wavelength of the transmitted signal. As the frequency of this signal rises, so the flux density of the electromagnetic waves (that is, the number of lines of electric and magnetic force per unit of area) rises also—with the result that a field-strength measuring device will pick up a stronger and stronger signal as the wavelength of the signal progressively shortens.

Unfortunately, the exact opposite of this increase in signal strength will be recorded by a receiving aerial situated quite close to the measuring device. The reason is that, as signal wavelength shortens, so the physical length of the aerial must be correspondingly reduced so that it can continue to resonate to the higher-frequency signal.

The result will be a steady reduction in the *aperture* of the dipole, as it is called. In other words, there will be less of it available to pick the signal out of the air. You can say, in fact, that

Effective Field Strength Varies Inversely as the Wavelength of the Radiated Signal

The Aerial—The Service Area (*continued*)

The third factor affecting field strength at a given point in the service area is the distance of that point from the receiving aerial. The rule is that:

Field Strength Varies Inversely as the Square of the Distance from the Receiving Aerial

Thus field strength at a point some distance away from the aerial is theoretically only a quarter of that at another point lying half-way along a straight line joining the first point to the aerial. Distance from the aerial has only been doubled, but field strength is reduced by a factor of four.

Normally, therefore, TV signals are strongest in areas close to the transmitter. Up to 15 to 25 miles away from it, the signal is generally strong enough to give a good and consistent picture with only a modest receiving aerial, and VHF frequencies in Bands 1 and 3 will be adequately picked up by indoor aerials mounted on the receiver itself. An outdoor aerial, however, will usually be required for reception of the UHF signals in Bands 4 and 5.

At distances beyond about 25 miles out to the optical horizon, signal strength is still adequate to give a good picture provided that a more efficient aerial is used.

The outermost limits of the service area depend partly on the height of the aerial above the surrounding countryside (the higher it is, the more distant its optical horizon), and partly on the frequency of the radiated signal. At the comparatively low frequencies employed in Band 1, the signal is able to bend slightly over the optical horizon and to follow the curvature of the Earth for a short distance beyond, so that even aerials situated below the horizon can sometimes receive the radiated signal. As the frequency of the signal increases, however, the rate at which its strength decays below the optical horizon rises fast. This is particularly true of the UHF signal, which tends to behave more like a beam of light and so will not readily bend round corners.

This *fringe area* just beyond the optical horizon lies normally some 35 to 40 miles distant from the transmitting aerial. Reception within it is unpredictable. Elaborate outdoor aerial systems are always required, with double-banked arrays having very high gain being needed to produce an adequate picture.

And yet, despite all the normally-accepted service area limits given above, the TV signals of BBC 1 have been known to be received with fair definition in Australia! What happens is that, at certain times of the day at certain seasons of the year and in certain conditions of weather, strongly ionized layers are formed in the atmosphere and move in a certain way around the globe. These ionized layers are capable of raising very considerably the critical frequency above which (see pages 4.68 and 4.69 of *Basic Electronics*) sky waves radiated from an aerial fail to be refracted back to Earth. With a convenient disposition of such layers around the Earth, the VHF signals reaching Australia would have got there by being bounced several hundred times between ionized layers in the atmosphere and the surface of the Earth, risking with every bounce failure to strike a waiting layer with suitable electrical properties or a normally reflective area of the Earth's surface.

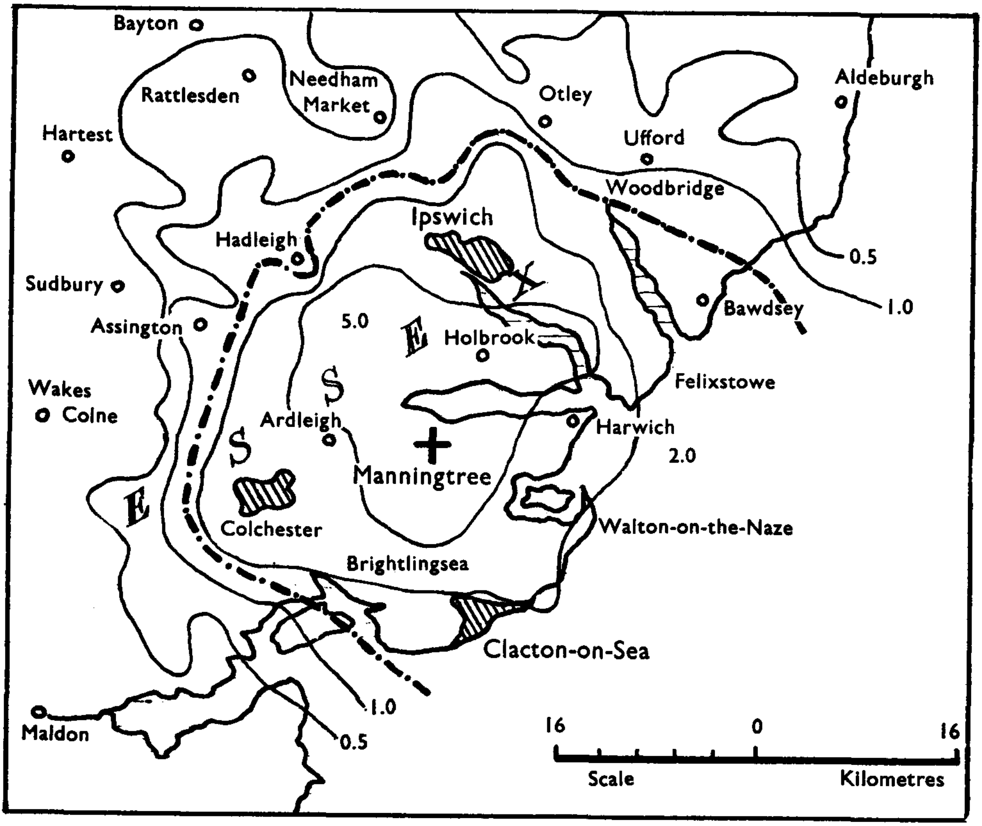
In freak reception of this kind, there are always large areas between transmitter and receiver in which no signal at all is received. As you learnt in *Basic Electronics* these no-signal areas form the *skip distance* of the transmitter.

The Aerial—Service Area (*continued*)

The zone limits detailed on the last page are not necessarily true of every transmitter anywhere in the world. Service area limits are affected by many other factors, particularly by the nature of the ground within the area, by its contours, and by the presence or absence of large structures such as tall office blocks or full gasholders.

The sketch map below, issued by the Engineering Information Department of the BBC, shows the service area of the BBC station at Manningtree (Essex), which transmits at VHF in Channel 4 on a vision frequency of 58·25 MHz and on a sound frequency of 61·75 MHz. Polarization is horizontal.

The thin unbroken contour lines show the average values of field strength in millivolts per metre of aerial length, measured with the receiving aerial fixed 30 ft above ground level. The heavy contour line broken by dots marks the limit of a service area free from interference from other channels for 90 per cent of reception time.



The service area of a transmitter is determined by making measurements of signal strength at a large number of points in the surrounding area, and by plotting these measurements on a map. Points of equal strength are joined up, and a contour line similar to the equal-height contours marked on an Ordnance Survey map is the result. The receiving aerial is mounted on a vehicle having an adjustable mast. Signals are measured with the aerial raised to a uniform height—usually 9 m above ground level. which is an internationally accepted approximation to the height of a receiving aerial mounted on the roof of a two-storey house.

The equal-signal-strength contour lines are known as *field strength contours*.

Operating Frequencies of TV Transmitters

The frequencies used for the broadcasting of radio and television programmes in all countries are allocated by international agreement, so as to minimize the chances of mutual interference. All the frequencies allotted lie within certain ranges (or **bands,** as they are called) of the electromagnetic spectrum, every band being identified by a number.

It must be remembered that the "traffic" which has somehow to be fitted into the air without avoidable mutual interference includes much besides the broadcast of news, instruction and entertainment to the general public. Channels are also provided for the Police; for the Armed Forces; for the Foreign Office and other Ministries of State; for Space Research; for the many users of Radar in its various forms; for the numerous and enthusiastic amateurs who glory in the name of "ham"; and for several other classes of special user as well.

As far as British TV is concerned, the frequency bands allocated to it are as follows:

Band 1, which ranges from 41 to 68 MHz (VHF)
Band 3, „ „ „ 174 to 216 MHz (VHF)
Band 4, „ „ „ 470 to 582 MHz (UHF)
Band 5, „ „ „ 614 to 854 MHz (UHF)

Band 1 frequencies are at present used exclusively by the BBC, and those in Band 3 by the Independent Television Authority (ITA). Bands 4 and 5 are reserved for use by the BBC and (one day) the ITA for the broadcasting of programmes on 625 lines and in colour. These allocations have been made—like all allocations of operating frequencies *within* a country—by purely British internal arrangement.

Each of the four Bands is itself divided into a number of smaller bands of consecutive frequencies, which are called **channels.** Every channel is in turn identified by a number. These channels are used by individual transmitting stations operating within a given frequency band. The London (Crystal Palace) transmitter of the BBC, for instance, operates on Channel 1 in Band 1; while the London (Croydon) transmitter of the ITA operates on Channel 9 in Band 3.

The maximum number of programmes which it is possible to transmit within a band of frequencies is determined by the number of channels into which that particular band can be divided. For technical reasons, the minimum spacing between channels in the 405-line system is 5 MHz. This means that Band 1, with its bandwidth of (68−41=) 27 MHz, could theoretically accommodate six programmes. In fact, however, the extra-wide spacing between Channels 1 and 2 allows only five—but this is a special case. Band 3, with its bandwidth of (216−174=) 42 MHz, can hold eight programmes at a time.

The minimum spacing between channels in the British 625-line system is 8 MHz, which means that 14 programmes could be accommodated in Band 4, and 30 in Band 5. But the provision of nation-wide coverage of a particular programme without mutual interference between transmitters requires the use of more than one channel for a given transmission.

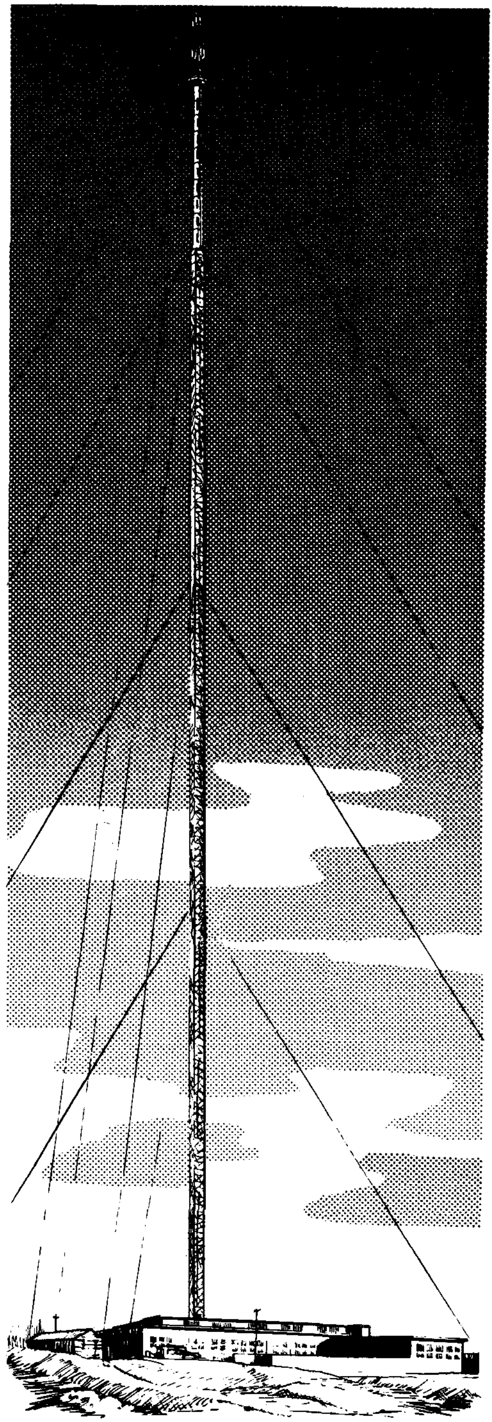
The result is that the number of different programmes which can be simultaneously transmitted on a national scale within a particular band cannot always be calculated by simple reference to the theoretical channel accommodation.

The Aerial—Physical Structure

The illustration on this page gives an impression of the 750-foot high mast supporting the aerial system at the BBC transmitting station at Holme Moss, situated high up in the Pennines on the borders of Yorkshire and Lancashire. Note the comparative size of the substantial one-storey buildings at the foot of the mast.

A powerful inland transmitter such as this, situated high up and in the midst of large centres of population on almost all sides, will be of the non-directional type having an almost circular service area.

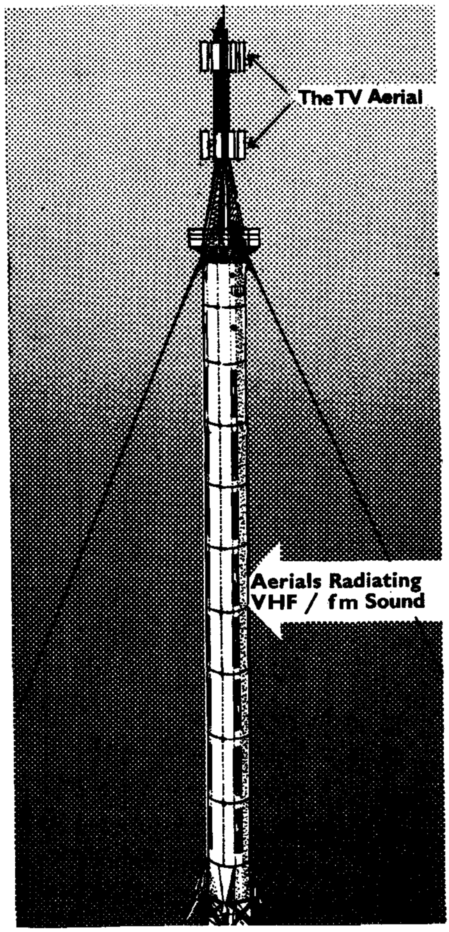
Pictured overleaf in closer detail are the topmost sections of the mast, on which the radiating elements themselves are situated.



The AERIAL MAST at Holme Moss

The Aerial—Physical Structure (*continued*)

The uppermost part of the big mast at Holme Moss consists of two separate sections, both indicated in the illustration to the right. The structure at the very top is the aerial used for radiating TV programmes in Channel 2 of Band 1. The aerial consists of a two-tier stack of half-wave dipoles, mounted in the vertical plane one above the other.



Note the two slender-looking wires attached to the mast just under the platform at the base of the TV aerial. There are actually four of these wires "anchoring" the mast at this level. They are in reality thick steel cables, each over 800 feet long. Their lower ends are fixed to huge concrete plugs let into the ground in a nearly-400 ft. radius from the foot of the mast.

Other groups of steel cables help to secure the mast at three other levels down its length. Their purpose is to help the mast withstand the tremendous pressures exerted by wind on a structure of such a shape.

The section of the mast immediately under the TV aerial forms the aerials used to radiate three sound-radio VHF/fm programmes in Band 2, which form part of the national network of the BBC. The section looks rather like a number of the small corner-turrets found in mediaeval castles, set one on top of another without their pepperpot roofs! The openings which resemble the "arrow-slits" in these structures are vertical slots, each of which acts as a half-wave dipole radiating in the *horizontal* plane.

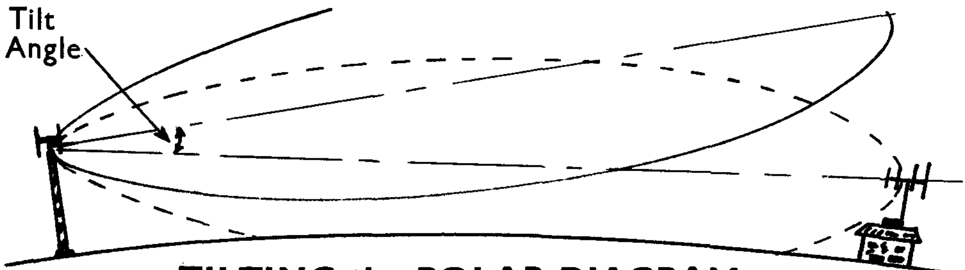
A still taller TV mast is that at Emley Moor, in Yorkshire, which carries (among other things) an aerial system for transmitting future VHF/fm radio broadcasts in Band 2, an aerial system for radiating TV signals in Band 3, and (at the very top) another aerial system for radiating TV signals at UHF in Bands 4 and 5. This mast is 1265 feet—nearly a quarter of a mile—high.

For reasons which you will see on the next page, dipoles are often stacked in tiers, one set above the other. On the Emley Moor mast, the section housing the stacked dipoles is enclosed in a fibre-glass tube 12 ft. in diameter. The object is to weatherproof the dipoles, and to make the servicing of them easier and safer. The effect is to make the mast look completely cylindrical from top to bottom.

The Aerial—Physical Structure (*continued*)

It is frequently desirable to distort deliberately the polar diagram of an aerial system in order to beam the radiated signal with greater power in one direction than in another. This might be made necessary by the nature of the terrain or by the concentration of the population in the service area. It is often essential in the immediate vicinity of the mast itself, for beaming can sometimes be too efficient and can send the radiated energy right over the heads of viewers living close to the aerial.

Distortion and downward tilting of the polar diagram can be achieved by stacking the dipoles in a special way, and by feeding them through different lengths of transmission line. This results in some of the dipoles receiving the signal fractionally later in phase than others, so altering the radiation pattern of the resulting electromagnetic wave.



TILTING the POLAR DIAGRAM

The radiating dipoles of the Sutton Coldfield (Birmingham) transmitter of the BBC are mounted in two tiers of four dipoles apiece, facing North—South—East—West respectively round the 750-foot mast, and with the two tiers placed one above the other exactly one wavelength apart. The dipoles are made of galvanized steel strip, and have 7·5 kW heaters to prevent ice from forming on them in winter. (At Emley Moor, the dipoles are of the rectangular-hollow-tube wave-guide type, to minimize electrical loss at ultra-high frequencies.)

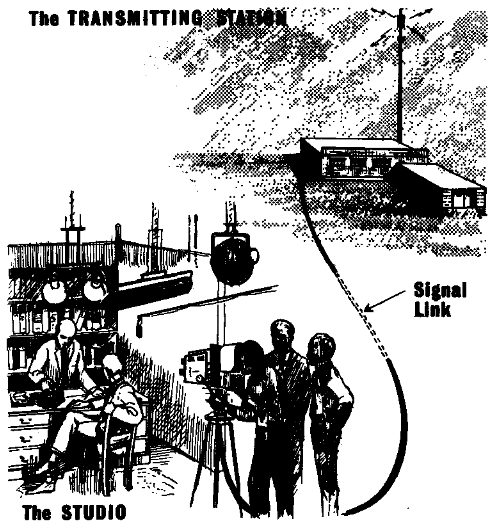
The Aerial—Precautions Against Breakdown

It is common practice nowadays to guard against the total breakdown of a transmitting station, affecting millions of viewers, by duplicating the entire transmitter set-up and by feeding the output of each pair of transmitters to a different half-section of the aerial system. Then if one transmitter or one part of the aerial system should fail, at least a fairly good signal would still be available from the other part.

Say, for simplicity of explanation, that one tier of dipoles in a two-tier aerial system is made completely separate, electronically, from the other. Each tier is served by a separate vision transmitter and by a separate sound transmitter, the outputs of which are combined in a separate combining unit and fed to the appropriate tier along separate transmission lines. In practice, a somewhat more complicated arrangement is required in order to balance the phase of the signals fed to the aerial system as a whole, and parts of one tier are "teamed up" with parts of the other. But the principle of duplicating the basic operations of the entire transmitting station is not affected.

The dipoles themselves are so designed that, should one-half of the system fail, the other can have the full power of the four transmitters (two vision and two sound) switched to it, and can radiate the resulting electromagnetic waves without any help from its faulty partner.

REVIEW of the Transmitter and Aerial

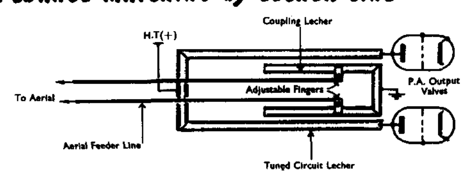


The Transmitting Station consists of not less than two *transmitters* (at least one for vision and one for sound) connected by special *feeders* to an *aerial.* The function of the station is to convert the video and audio signals received by landline or SHF radio link from the studio into electromagnetic waves, and to radiate these waves to receiving aerials situated within the service area of the station.

The Vision Transmitter produces a carrier wave of very stable frequency and amplitude. The amplitude of this carrier is then modulated by the video signal from the studio, and the resulting *vision signal* is raised to a high power in a number of power amplifiers. The signal then passes in turn through an impedance-matching stage, a sideband filter circuit and a combining unit on its way through several hundred feet of feeder to the aerial.

The purpose of the *Impedance-Matching* stage is to reduce the output impedance of the transmitter to approximately the Z_0 of the feeder. The value of this Z_0 is normally chosen so that it matches the impedance of the aerial at the point where the signal is fed into it. Matching is normally done at VHF by means of a transformer, at UHF by means of lecher lines.

IMPEDANCE MATCHING by LECHER LINE



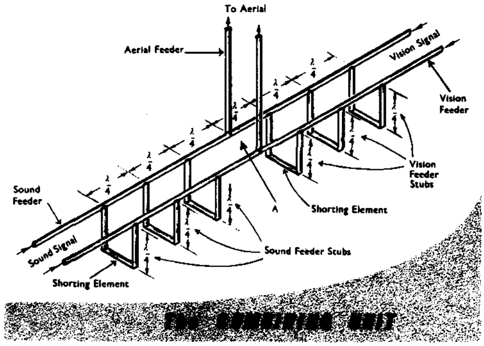
Vestigial Sideband Transmission is a technique used to reduce the bandwidth required by the radiated vision signal, with the object of fitting a greater number of channels into a given band of frequencies. It is achieved in the sideband filter circuit by suppressing part of one of the two sidebands which are produced during modulation of the vision carrier. Both of the sidebands produced during modulation of the sound carrier are transmitted in full.

The Sound Transmitter uses the signals produced by the microphones in the TV studio to modulate either the amplitude of its carrier (in the 405-line system) or the frequency of its carrier (in the British 625-line system). There are two main types of frequency modulation—the *direct* type in which the frequency of an ordinary LC-type oscillator is directly modulated and then stabilized in a later stage, and the *indirect* type in which a more stable type of crystal oscillator is (though with more difficulty than before) modulated in a later stage.

In both types, the *frequency* of the sound carrier is made to vary in accordance with changes in the *amplitude* of the audio signal.

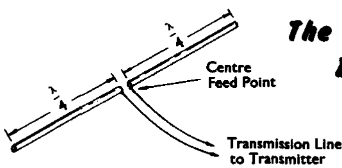
REVIEW of the Transmitter and Aerial (*continued*)

The task of the *Combining Unit* is to feed the separate sound and vision signals into a common feeder line, so that they can be radiated together from a common aerial. It is necessary to ensure that the vision signal cannot get back down the line into the sound transmitter, nor the sound signal down the line into the vision transmitter. The job is done by means of quarter-wave short-circuited stubs situated at intervals of one-quarter of the wavelengths of the respective signals back along each line from their point of function.



Electromagnetic Waves are generated as a result of the rapid build-up and collapse of the electric and magnetic fields set up round an aerial when a powerful alternating current is fed into the aerial. The two fields are at right angles to one another, and the wave is said to be *polarized* by reference to the inclination of its electric field.

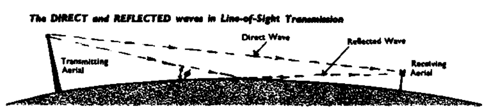
The Half-Wave Dipole is the shortest length of aerial in which the conductor arms behave as a tuned circuit resonant at the frequency which it is desired to radiate. The signal is generally fed to its centre point.



The Half-wave Dipole

When an aerial radiates electromagnetic waves, the radiation is always stronger in some directions than in others. Aerials are said to be *directional* along their lines of strongest radiation. The *directivity* of an aerial system in a desired direction can be improved by such devices as stacking the dipoles one above the other, or by placing reflectors and directors respectively behind and in front of every dipole in the system.

The *Service Area* of a TV transmitter theoretically corresponds with the limits of the optical horizon in all directions from the top of the aerial mast, but is in practice much affected by the nature of the terrain. Signals travel by *line of sight transmission* from the transmitting to the receiving aerials in two types of wave—the *direct* and the *reflected* waves.



The Operating Frequencies used in British TV are as follows: BBC 1 and ITV broadcast on 405 lines at VHF in Bands 1 (41—68 MHz) and 3 (174—216 MHz) respectively; BBC 2 broadcasts (and all future 625-line programmes) at UHF in Bands 4 and 5 (470—854 MHz).

In the 405-line system, the frequency of the sound carrier is 3·5 MHz below that of the corresponding vision carrier. In the British 625-line system, it is 6 MHz above it.

§ 8: SIGNAL BANDWIDTH

You will recall that the picture elements of a CRT scanning device are individually extremely small, and that the total number of them contained in a single picture image can run into many hundreds of thousands. The scanning beam of the camera tube has to convert all these hundreds of thousands of picture elements into equivalent electrical signals, and it has to do so within the repetition period of a single picture.

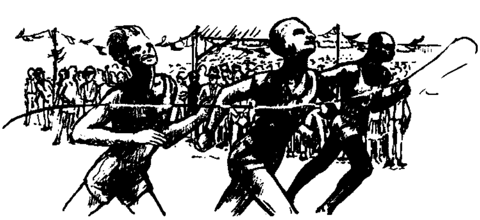
Since this repetition period is as short as one-twenty-fifth of a second, it is clear that the rate at which picture elements need to be converted into electrical signals is enormously rapid. To take a practical example: If the image displayed on the target of a camera tube is composed of 400,000 elemental areas, and if the complete image is scanned once every twenty-fifth of a second, the rate at which conversion must take place is $400{,}000 \times 25$, or **10 million picture elements per second.** You must now find out why this formidable conversion rate demands **a much greater frequency bandwidth for the radiated vision signal than is needed for radiation of the sound signal.**

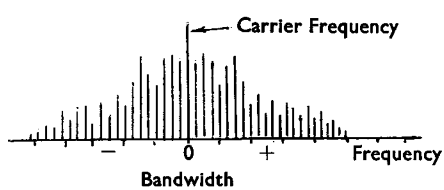
Recall what you learnt about amplitude modulation in Part 4 of *Basic Electronics.* You learnt, in particular, that when an r.f. carrier is amplitude-modulated, the effect is to add new frequencies to the transmitted signal in addition to the frequency of the carrier itself. These extra frequencies, you read, are called sidebands; and it is they —not the carrier frequency itself—which contain the intelligence of the transmission. You also found that the frequency bandwidth of the modulated carrier (that is to say, the range of frequencies extending between the limits of the upper and lower sidebands) increases as the frequency of the modulating signal increases.

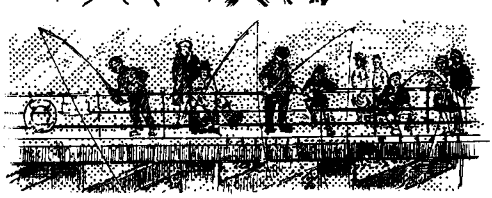
The same effect occurs when the vision signal from a TV station is transmitted from an aerial—only in this case the sidebands developed are very much wider than those produced by a radio transmitter because of the much higher frequency.

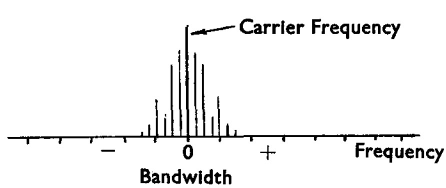
The actual width of the sidebands produced by a TV transmitter depends on *the rapidity with which the elemental areas of the scene being televised are being converted into electrical signals.* This, in turn, depends largely on the tonal composition of the scene. When this is, say, a quiet seascape on a dull day, a great many of the picture elements composing the scene will merge into one another in a kind of overall grey. From the point of view of the scanning beam this reduces their number, and so the rapidity with which they have to be converted into electrical signals.

To put the point in more homely terms: You need a greater frequency bandwidth to televise the final of the men's 100 metres on a sunny day at the Olympic Games than you do to televise an angling competition off the pier at Southend in dull, overcast weather.









The Frequency Content of the Video Signal

You know that the video signal sent to the transmitter for radiation is composed of two elements: (*a*) a sequence of regularly-spaced synchronizing pulses for line and (much less frequently) field scans, and (*b*) a picture signal of continuously varying amplitude. It is the task of the designers of a TV set to determine the minimum bandwidth which such a video signal will require, in the most exacting conditions of tonal contrast which the camera is likely to be asked to handle.

There is no difficulty about the two sync pulses, which form distinct and regularly-recurring components in the frequency spectrum corresponding to the repetition rates of the line and field sync pulses. As you know, the repetition rate of the *line* sync pulses is determined by the number of pictures presented per second, divided by the number of lines composing a picture. The *field* sync pulse repetition rate is twice the number of times a complete picture is presented per second. In all European TV systems, this picture presentation rate is 25 times a second, so the field sync pulse repetition rate is 50 times a second.

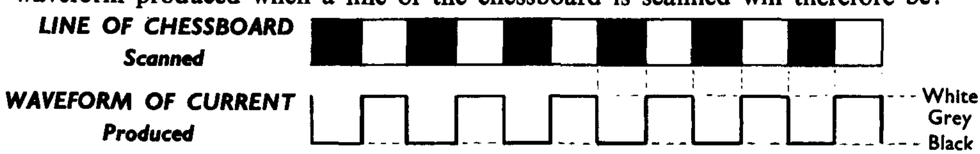
Neither type of sync pulse, therefore, causes any large change in the frequency spectrum; so neither causes the designer any difficulty in this respect. The only proviso is that the bandwidth selected must be wide enough to accept some of the harmonic frequencies contained in the rectangular sync pulses, in order to preserve their "squareness". For if the shape of the sync pulses is unduly distorted, accuracy of synchronization will be impaired.

It is the frequency components of the *picture signal* which in practice determine the signal bandwidth which a TV system requires for efficient operation.

You know that it is necessary, if you are to get good definition of the reproduced picture, that the bandwidth of the transmission shall be wide enough to accommodate the highest frequencies produced by the camera. It is therefore usual to determine the bandwidth needed by a TV system by reference to the most severe tonal conditions which the system could theoretically encounter in practice.

Such conditions are represented by a scene composed entirely of rows of alternate black and white squares arranged in chessboard fashion, as shown in the illustration below. Each of these squares represents an elemental area, and is assumed to be of a size equal to the area of the scanning spot (which is very small indeed).

As the scanning beam moves across the chessboard scene, a pulse of current will flow every time a white square is scanned, and a minimum no-signal current (or even no current at all) will flow when a black square is scanned. The shape of the current waveform produced when a line of the chessboard is scanned will therefore be:



The illustration above assumes that the camera used produces a positive-going picture signal. For a camera producing a negative-going picture signal, the current waveform is simply shifted along one square to the right.

The Frequency Content of the Video Signal (*continued*)

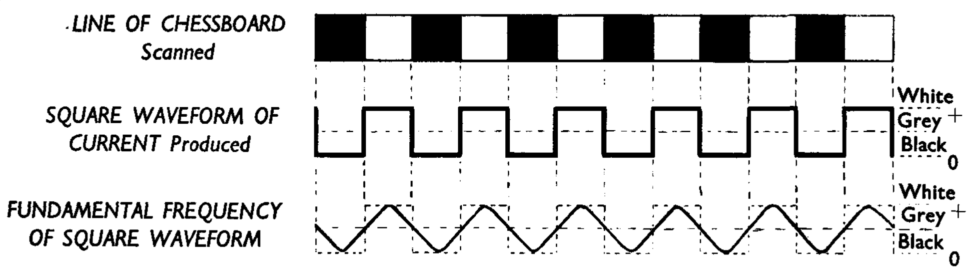
You know from *Basic Electronic Circuits*, Part 1, that a square wave such as that at the foot of the preceding page is in reality a *composite* wave, made up of a fundamental sine wave having the same period as the square wave, plus a large number of harmonics of the sine wave. The frequencies of these harmonics, you will recall, are always *multiples* of the frequency of the fundamental; and the more of them there are present in a waveform, the nearer will that waveform attain to "squareness".

It follows that the square waveform theoretically produced by a scan of one line of the chessboard contains a large number of harmonics of the fundamental sine wave, and that to transmit all these harmonics would involve an extremely high modulating frequency. The bandwidth of a carrier modulated by such a high-frequency signal would need to be very large—so large as to cause considerable problems of channel allocation, and of design in both the transmitter and receiver.

A perfect picture of the chessboard scene cannot, therefore, be economically transmitted by a normal TV system. Fortunately this does not matter so much as you might expect, for in ordinary everyday scenes contrasting tones as severe as those of the chessboard practically never occur. Something a good deal lower than theoretically-perfect definition can therefore be accepted.

It has, in fact, been found that a picture of acceptable quality can be transmitted if all (or nearly all) the harmonics of the chessboard-produced square wave are omitted, and *if a bandwidth be chosen for the system which is wide enough to accommodate the fundamental frequency of the square wave only.*

This fundamental frequency is shown in the illustration below.



The Fundamental Frequency of the SQUARE WAVE

Given a camera producing a positive-going picture signal, every positive peak of this sine wave represents a white dot in the tonal composition of the scene, and every negative peak a black dot. If the picture signal is negative-going, these polarities are of course reversed.

The problem of determining the maximum frequency which the picture signal is ever likely to produce (and therefore the minimum bandwidth which the video signal will require) thus resolves itself into a matter of calculating the fundamental frequency of the signal produced when the chessboard is scanned.

You should now see how this can be done.

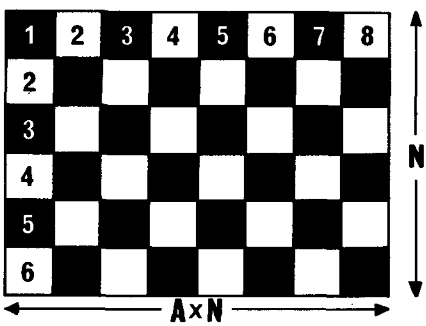
Calculating Maximum Picture Signal Frequency

The first step in determining the maximum picture signal frequency produced when the chessboard is scanned is to calculate the total number of picture elements contained in the scene. Obviously, one of the factors affecting this total is the number of scanning lines composing the picture, for this governs the number of elements which can be fitted into the *height* of the picture. Call this number N.

Now recall that the ratio of the *width* of the observed picture to its height is known as its *aspect ratio* (A). Whatever the actual dimensions of the picture, its width will always be A times its height. If the height of the picture contains N contiguous elements, each square in shape, the number of elements in any one line across the width of the picture must be $A \times N$.

With the picture itself composed of N lines, the total number of elements in the complete picture must be N times the number of elements contained in any one line, or $N \times (A \times N) = AN^2$.

You will follow the basic reasoning of this quite clearly if you look at the simplified sketch of a TV picture below.



With the Aspect Ratio 4:3, Total Number of Elements in the Picture is

$$AN^2 = \frac{4}{3} \times 36 = 48$$

Now the signal waveform produced by a scanning spot moving across an individual line of the chessboard scene is composed of two distinct regions, one representative of the white elemental areas and the other representative of the black areas. The instantaneous signals produced from the two regions will be of opposite polarity, the signal representing black lying below the mean level of grey, and the one representing white lying above it.

Since the black and white elements are adjacent to one another, the signal waveform produced from every line of the chessboard will consist of a repetitive sequence of alternate positive and negative signals. *One cycle of the signal* is therefore completed for every pair of adjacent elements—one black, one white; and the number of cycles of the signal waveform produced from the complete picture will be exactly *half* the number of elements contained in the picture. In other words, it will be $\frac{AN^2}{2}$.

The number of cycles of the signal waveform produced during the scanning period of the complete chessboard scene represents the maximum picture signal frequency, expressed in terms of *cycles per picture*. You have only to multiply that number by the picture repetition rate (P, expressed as the number of pictures scanned per second), and you get what you are looking for—namely, the maximum picture signal frequency expressed in *cycles per second*.

The complete formula is thus

$$\textbf{MAXIMUM PICTURE SIGNAL FREQUENCY} = \frac{PAN^2}{2} \textbf{ cycles per second}$$

Calculating Maximum Picture Signal Frequency (*continued*)

The formula derived at the foot of the preceding page can be used to calculate the maximum picture signal frequency (f_{max}) of any TV system by substituting the appropriate values for picture repetition rate, aspect ratio and number of scanning lines.

In the 405-line system, the values are: P = 25, A = 4/3; N = 405. Therefore

$$f_{max} = \frac{PAN^2}{2} = \frac{4 \times 25 \times 405 \times 405}{3 \times 2}$$
$$= 2{,}733{,}750 \text{ cycles per second, or Hertz}$$

which is approximately equal to **2·7 MHz.**

In practice, there is room to increase the vision signal bandwith of the 405-line system to **3 MHz,** which permits transmission of the maximum picture signal frequency, plus a small number of its harmonics as well.

In the British 625-line system, on the other hand, in which the values are P = 25, A = 4/3; and N = 625

$$f_{max} = \frac{PAN^2}{2} = \frac{4 \times 25 \times 625 \times 625}{3 \times 2}$$
$$= 6{,}510{,}417 \text{ Hertz}$$

which is approximately equal to **6·5 MHz.**

This is a bandwidth too great to be fitted conveniently in the channel available, so part of the f_{max} is sacrificed and the width of the upper sideband (which carries the intelligence) is limited to **5·5 MHz.** Some slight loss of definition results on the screen of the picture tube—rather as if you were to use a film of coarser grain in your holiday camera.

In both the above calculations, you will note, two factors have been ignored. The first is that the number of lines which are in practice lost in the field blanking periods reduces N, which *increases* the value of A. The second is that the proportion of each line which is inactive during the line blanking periods *reduces* the value of A. The degree of error so introduced is on balance small and may (in these two cases) be ignored.

Note also the importance which the technique of *interlacing* assumes in evaluating the equation $f_{max} = \frac{PAN^2}{2}$, and so establishing the bandwidth needed by a particular TV system.

You know that, in the British and all other European TV systems, the presentation rate of the picture (which needs to be a minimum of 50 pictures a second if objectionable flicker is to be avoided) is in practice reduced to 25 pictures a second without harm to the received picture. Thus P (the picture repetition rate) is effectively halved by interlacing, with consequent reduction of the bandwidth required for the system.

To take a simple example. If it were not for interlacing, every one of the lines making up the picture in the British 625-line system would need to be presented not less than 50 times a second if flicker were to be avoided. The equation would then be:

$$f_{max} = \frac{4 \times 50 \times 625 \times 625}{3 \times 2} \text{ Hz, or nearly } \mathbf{13\ MHz}$$

instead of the 6·5 MHz which you know to be all that is actually needed.

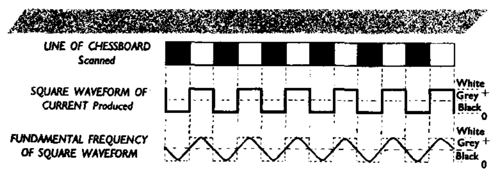
It is easy to see the important part which the interlacing technique has played in easing the problems of channel congestion.

REVIEW of Signal Bandwidth

The bandwidth **required for transmission of the vision signal is much greater than is that needed for transmission of the sound signal; and the higher the definition of the transmitted picture, the higher will be the bandwidth required.**

The reason is that the many hundreds of thousands of elemental areas contained in the picture have to be converted into equivalent electrical signals within the very short space of time which the beam takes to scan the scene. In other words, *the conversion rate* of the elemental areas is very high. A high conversion rate calls for high picture-signal frequency; and this, in turn, requires that the vision signal at the transmitter shall have a wide sideband.

The maximum frequency content **of the video signal is generated by a TV camera when it is set to scan a scene composed of the most severe tonal contrasts it is possible to devise. Such a scene is accepted to be a chessboard pattern of alternate black and white elemental areas, each square in shape and each the exact size of the cross-section of the scanning beam.**



The Fundamental Frequency of the SQUARE WAVE

The signal frequency so produced is here designated f_{max}.

The formula for calculating the maximum frequency content of a TV system when it is scanning the chessboard scene is

$$\boxed{f_{max} = \frac{PAN^2}{2}}$$

where P is the picture repetition rate (in number of pictures presented per second), A the aspect ratio of the observed picture, and N the number of lines composing the picture. Note that, because f_{max} is proportional to the *square* of the number of lines used in a given TV system, any 625-line system will require a much greater bandwidth for satisfactory transmission than will a 405-line system.

The absolute size of the f_{max} of a TV system—and therefore of the bandwidth it will require for satisfactory reception—is much reduced by the technique of interlacing. If 50 pictures per second need to be presented to the observer's eye to avoid the sensation of flicker, this condition can be satisfied by presenting instead 50 fields interlaced so as to form only 25 pictures.

The value of P in the $\frac{PAN^2}{2}$ equation is thereby halved, and with it the maximum bandwidth needed by the system.

INDEX TO PART I

Aerial, Transmitting 1.114 *et seq.*, 1.126
Afterglow 1.29
Aspect Ratio 1.36, 1.134

Back Porch 1.70
— Projection 1.96
Band, Frequency 1.125
Bandwidth, Signal 1.131 *et seq.*
Black-Level Reference Signal 1.48
Blanking Pulse 1.45, 1.57
— Waveform 1.69, 1.72
Bright-Up 1.31
Burn-In, Image 1.57

Caesium 1.12, 1.38, 1.42, 1.52
Camera Chain 1.89
— Control Unit 1.92
— Tube 1.29, 1.37
Carrier Modulation 1.101
— Wave 1.100
Central Apparatus Room 1.85
— Control Room 1.82, 1.85
Channel, Frequency 1.125
Close-up 1.95
Colour (Nature of) 1.8
Cutting 1.93

D.C. Level 1.48
Decelerator Grid 1.55
Definition 1.16
Defocusing 1.94
Directivity 1.120
Director 1.121
Dissolve 1.94
Dynode 1.39

Electromagnetic Waves 1.115
Electron Gun 1.41
— Multiplier 1.39, 1.56
Equalizing Pulses 1.78
Eye, Human (How it Works) 1.17

Fade-in, fade-out 1.93
False Perspective 1.97
Feeders, Aerial 1.113
Field 1.32
— Flyback Path 1.72
— Frequency 1.32
— Strength 1.122 *et seq.*
— — Contour 1.124
— Sync Pulse 1.72 *et seq.*
Final Anode (of Iconoscope) 1.41
Final Transmission Picture 1.87
Flicker 1.26
Flyback Period 1.30
— Time 1.69, 1.72
Focus Coil 1.52
Frame 1.32
Frequency Content (of Video Signal) 1.132 *et seq.*
— Deviation 1.104
Frequency Multiplier Circuit 1.100
Fringe Area 1.123
Front Porch 1.70
Fundamental Frequency 1.133

Half-Line Pulses 1.73
Half-tone Photo-engraving 1.15
Half-wave Dipole 1.114 *et seq.*
Heat (Nature of) 1.8

Iconoscope Camera 1.40 *et seq.*
Image Accelerator Grid 1.52
— Orthicon Camera 1.49 *et seq.*
— Sticking 1.57
Inlay 1.97
Interlaced Scanning 1.32 *et seq.*

Lecher Line 1.108
Lens Turret 1.58
Light (How Converted into Signal) 1.12
— (How Produced) 1.9 *et seq.*
— (Nature of) 1.7
Lighting Supervisor 1.88
Line-of-Sight Transmission 1.121
Line Scan Period 1.36
— Scanning Frequency 1.35
— Sync Pulse 1.69 *et seq.*

Master Sync Pulse Generator 1.90
Maximum Picture Signal Frequency 1.133
Microphone 1.6
Monitors 1.87
Montage Effects 1.96 *et seq.*
Mosaic 1.37, 1.42

Nipkow Disk 1.27

Operating Frequencies (of British T.V. Transmitters) 1.125
Optical Horizon 1.121
— Window 1.41, 1.60
Overlay 1.97

Panning 1.94
Pedestal 1.76
Persistence of Vision 1.18
Persuader Grid 1.56
Photo-cathode 1.13, 1.37, 1.52
Photocell 1.13
Photo-conductivity 1.14, 1.61 *et seq.*
Photo-conductive Lag 1.63
Photo-electricity 1.12
Photo-multiplier 1.39
Photosensitivity 1.12
Picture 1.32
— Elements 1.16
— Frequency 1.32
— Signal 1.44, 1.64
— Sync Ratio 1.76
— Tube 1.29
Polar Diagram 1.120

Polarization (of Transmitted Wave) 1.118
Post-Sync Field Blanking 1.75
Presentation Suite 1.85
Producer 1.87
Production Control Room 1.87
— Studio 1.85

Raster, Scanning 1.30
Reactance Modulator 1.104
Reflector 1.121
Resolution 1.16, 1.46, 1.63
Resolving Power 1.16
Retrace Time 1.69

Scan 1.29
Scanning 1.29 *et seq.*
— Frequencies 1.35
— Raster 1.30
Secondary Electrons 1.38
— Emission 1.38
— — Ratio 1.38
Selenium 1.14
Sensitivity (of Iconoscope) 1.46
Sequential Scanning 1.24
Service Area 1.121 *et seq.*
Shading Signals 1.48
Sidebands 1.131
Sideband Filter 1.109
Signal Bandwidth 1.131
— Load Resistor 1.45
— Plate 1.42, 1.60
— Routing 1.82
Silhouette Pulse 1.97
Skip Distance 1.123
Sound Signal 1.5
— Supervisor 1.88
— Transmitter 1.102 *et seq.*

Spectral Colours 1.8
Spectrum of Visible Light 1.8
Spill Light 1.96
Studio, Television 1.81 *et seq.*
— Floor 1.86
— Manager 1.86
Switching Centre 1.82
Sync Pulses 1.68

Talk-back Apparatus 1.92
Target 1.29, 1.37, 1.54, 1.60
— Mesh 1.52, 1.60
Telecine Machine 1.84
Tilt 1.95
— Angle 1.128
Timebase 1.29
Tonal Content (of Scene) 1.15
Trace 1.29
Transmitter, Vision 1.100 *et seq.*
Transmitting Aerial 1.114 *et seq.*, 1.126

Vestigial Sideband Transmission 1.109
Video Signal 1.68
— Effects 1.98
Video-Tape Machine 1.84
Vidicon Camera 1.60 *et seq.*
Viewfinder 1.58, 1.60
Vision Mixer 1.87
— Signal 1.5
— Supervisor 1.88
— Transmitter 1.100

Wall Anode 1.55, 1.60
Waveband of Visible Light 1.7
Wipe 1.97

Zoomar 1.58, 1.95

BASIC TELEVISION

Part 2

A Basic Training Manual developed by

H. A. COLE, C.Eng., M.I.E.R.E.,
working in conjunction with
the Editorial and Art Staff of the Publishers.

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PREFACE

The aim of this Series on *BASIC TELEVISION* is to explain in simple language the physical principles which make television possible and the way in which a typical television system works—from the generation of the signal in the TV camera to the final presentation of the picture on the screen by your own fireside. The Series is based on the two TV systems working in Great Britain today—the very-high frequency (VHF) one working on 405 lines per picture and the ultra-high frequency (UHF) one working on 625 lines per picture. The receiver considered in Parts 2 and 3 is the British Dual-Standard Receiver which is capable, on operation of the "*Standard Selection*" control, of receiving programmes on either of these two considerably different systems.

Two decisions of particular importance had to be made in planning the Series. The first was to describe the working of the TV receiver almost wholly in terms of valves, even though in many of the latest single-standard and colour receivers the thermionic valve is being progressively replaced by semiconductor devices. This decision was made on two grounds. The first was that a large majority of the millions of receivers operational in Britain in the second half of 1971 are wholly or mainly valve-operated rather than transistorized and that, for technical and economic reasons which are more fully discussed in the final Section of Part 3 "TRENDS IN TV RECEIVER DESIGN", the valve will in all probability continue to play an important part in TV receivers, especially in those built on the Dual-Standard principle, for a significant number of years to come. The second reason was that, since the **COMMON-CORE** Series as it exists at present is planned on the basis of explaining the working of electronic devices in terms of current flow through a valve, it was desirable to keep this account of the basic principles on which television works compatible with the foundation **COMMON-CORE** volumes in their present form.

The other major decision in planning *BASIC TELEVISION* was to cover black-and-white ("monochrome") transmission and reception only, in the interest of keeping the descriptions of the various stages in the studio camera, the transmitter and the receiver relatively simple and relatively short. With the basic principles involved thus established (it is hoped) in the reader's mind, a further Series on *Basic Colour TV*, fully transistorized to reflect modern progress, is currently planned.

Most of the measurements given in the Series have been expressed (or in Part 1, which was first published in 1967, re-expressed) in SI Metric units. In particular, "Hertz" and "MHz" have been used in place of "cycles per second" and "Mc/s" throughout. But certain measurements either familiar to the viewer (*e.g.*, the sizes of picture tube) or else representative of orders of magnitude rather than of precise distances have been left in inches, miles, etc., as being more likely in that form to give the ordinary reader a clear picture of the point being made.

The Series has been written and illustrated to take its place in the growing **COMMON-CORE** Series of Illustrated Training Manuals on subjects connected with electricity and electronics. Originated in the United States by the distinguished New York firm of technical education consultants and graphiological engineers,

VAN VALKENBURGH, NOOGER & NEVILLE, INC.

the twenty-one Manuals of which the **COMMON-CORE** Series now consists have already sold over 1,500,000 copies in their British and Commonwealth editions. Six of the Manuals have been wholly conceived, written and illustrated in the United Kingdom; while all the remainder have been extensively rewritten to conform with British terminology and notation.

The *BASIC TELEVISION* Manuals presuppose in the reader a working knowledge of the contents of the foundation volumes of the **COMMON-CORE** Series, principally the five Parts of *BASIC ELECTRICITY* and the six Parts of *BASIC ELECTRONICS.* Prior acquaintance with the two-part series *BASIC ELECTRONIC CIRCUITS* will also prove useful when the operation of the TV receiver is studied in Parts 2 and 3.

The *BASIC TELEVISION* Series has been written, in conjunction with the editorial staff of the Publishers, by **Mr. H. A. Cole**, a Senior Scientific Officer in the Electronics and Applied Physics Division of the Atomic Energy Research Establishment at Harwell. Mr. Cole is a Chartered Engineer, and a Member of the Institution of Electronic and Radio Engineers. All illustrations of a technical nature have been drawn by Mr. Cole himself, with the Art Department of THE TECHNICAL PRESS responsible for their "decoration" and captioning.

TABLE OF CONTENTS

Section		Page
9	Introducing the TV Receiver	2.1
10	The Receiving Aerial	2.17
11	The Tuner	2.59
12	The IF Amplifier	2.83
13	The Sound Signals	2.110
14	The Video Detector	2.116
15	The Video Amplifier	2.122
16	Coupling the Video Signal to the Picture Tube	2.136

The COMMON COMMON-CORE **CORE Series**

of Basic Training Manuals
embraces so far the following titles:

BASIC ELECTRICITY

BASIC ELECTRONICS

BASIC SYNCHROS AND SERVOMECHANISMS

BASIC ELECTRONIC CIRCUITS

BASIC RADAR

BASIC INDUSTRIAL ELECTRICITY

BASIC TELEVISION

Foreword on International TV Systems

The television set round which this Series has been written is the so-called *British Dual-Standard Set*, which is capable of receiving signals on two distinct line-systems—the 405-line and the British 625-line systems.

If you wonder at the emphasis placed on the word "British" in that phrase, "the *British* 625-line system", the reason for it is that it has regrettably not yet been possible to secure international agreement on all the technical details of any standard 625-line system.

For some time past, it has been the aim of the *C C I R* (*the Comité Consultatif International des Radio*, or *International Radio Consultative Committee*) to persuade all the countries of the world to adopt a common TV system, on the grounds that it would be of great benefit to everyone from the point of view of convenience, ease of programme exchange, and manufacturing economy. Although complete agreement is still a long way off, progress has certainly been made over the past few years.

There are at present seven major TV systems in the world: the American 525-line, the French 625-line, the French 819-line, the West European 625-line, the East European 625-line, the British 405-line, and the British 625-line systems. The British 405-line system is due to be gradually discontinued over the next few years and will eventually be replaced by a 625-line system.

Unfortunately, not all European countries—even the Western ones—agree on the technical details of a standard 625-line system. It is true that they agree on such important features as aspect ratio, scanning sequence, method of interlacing and a few others; but differences still exist over (for example) the choice of vision bandwidth, channel spacing, sound-to-vision carrier spacing, and the degree of modulation which shall correspond to black level. These differences, though not very great, can sometimes prevent satisfactory exchange of two 625-line programmes. For example, the 625-line system employed by Belgium and France uses amplitude modulation for the sound carrier, whereas all other European countries use frequency modulation. Similar differences exist elsewhere in Europe over the relative spacing of the sound and vision carriers.

The Western European and Eastern European systems differ mainly in the values chosen for channel width and vision bandwidth. The Western European system uses a 5 MHz vision bandwidth and 7 MHz channel spacing, whereas the Eastern European system uses a 6 MHz vision bandwidth and 8 MHz channel spacing.

The British 625-line system differs from both European systems in that it uses a 5·5 MHz vision bandwidth and 8 MHz channel spacing. Other differences concern the width of the vestigial sideband and the setting of the black level.

§9: INTRODUCING THE TV RECEIVER

You learnt in Part 1 of *Basic Television* the general principles on which TV works. You saw how the sound and vision signals are produced in the studio or processed there after an outside broadcast, and you learnt about the various stages through which these signals must pass before they are radiated by the transmitter. At the end of Part 1, you left the sound and vision signals quite literally "in the air" between transmitter and receiver.

You must now see how these signals are picked up by the aerial, and how they are thereafter resolved in the receiver into the picture you wish to view and into the accompanying sounds which, with the picture itself, will reproduce by your fireside the complete scene enacted in the distant studio.

Reduced to its essentials, the purpose of a television receiver is to select from the many signals which are always present in the air that one signal which carries the desired train of information, and then to decode and process this signal in such a way that it will cause to be reproduced an audible and visible image of the studio scene. To achieve that purpose, the receiver must be capable of performing certain basic functions.

THE BASIC REQUIREMENTS of a TV Receiver

First, as has been said, the appropriate signal in the required channel must be *selected* from the other signals present at the aerial, and then *amplified* to a usable level.

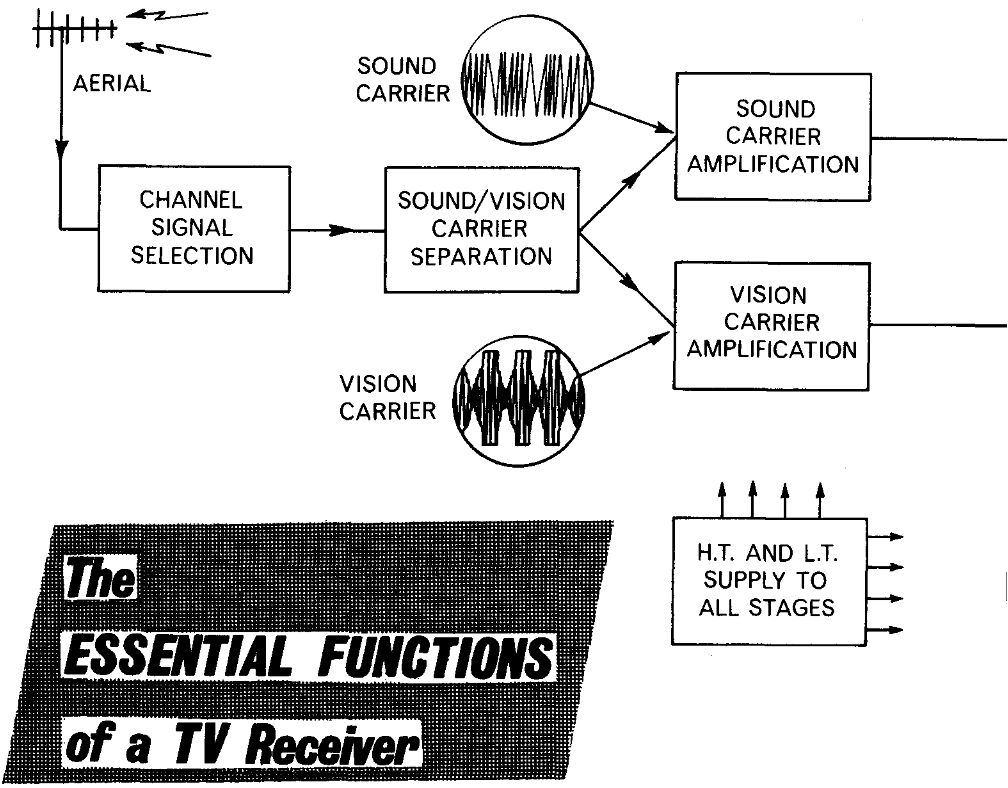
Second, the sound and vision carriers must be *separated* from one another, and passed to their respective sound and vision circuits for *demodulation*—namely, the extraction from the carriers of the audio and video modulations which contain the required intelligence. The resulting *audio signal,* after further amplification, is taken to the loudspeaker and made to modulate it so that it will reproduce audibly the audible content of the studio scene. The *video signal,* also after further amplification, is used to modulate the intensity of an electron beam scanning the raster of the picture tube, and so to reproduce visibly the visible part of the studio scene.

Third, sync pulses extracted from the video signal must be made to *synchronize* both the operating frequencies and the starting times of the line and field scanning circuits which produce the raster of the picture tube.

Lastly, separate *power supplies* must be connected to produce both the very high voltage needed on the picture tube, and the much lower HT voltage required by all the other circuits in the receiver.

The large illustration across the next two pages shows in block diagram form these various essential functions of the TV receiver. Note that the illustration is in no sense a circuit diagram. You will find that the circuits and blocks of circuits which have been developed to enable the various functions of the receiver to be performed differ in some important respects from the layout shown overleaf.

The Essential Functions of a TV Receiver



The broad principles of operation of a TV receiver are similar to those of the amplitude-modulated radio receiver you learnt about in *Basic Electronics*. Both make use of the superheterodyne principle for achieving high gain and good selectivity for both the sound and the vision signals. Both use similar circuits for such purposes as signal detection, suppression of noise, and automatic gain control.

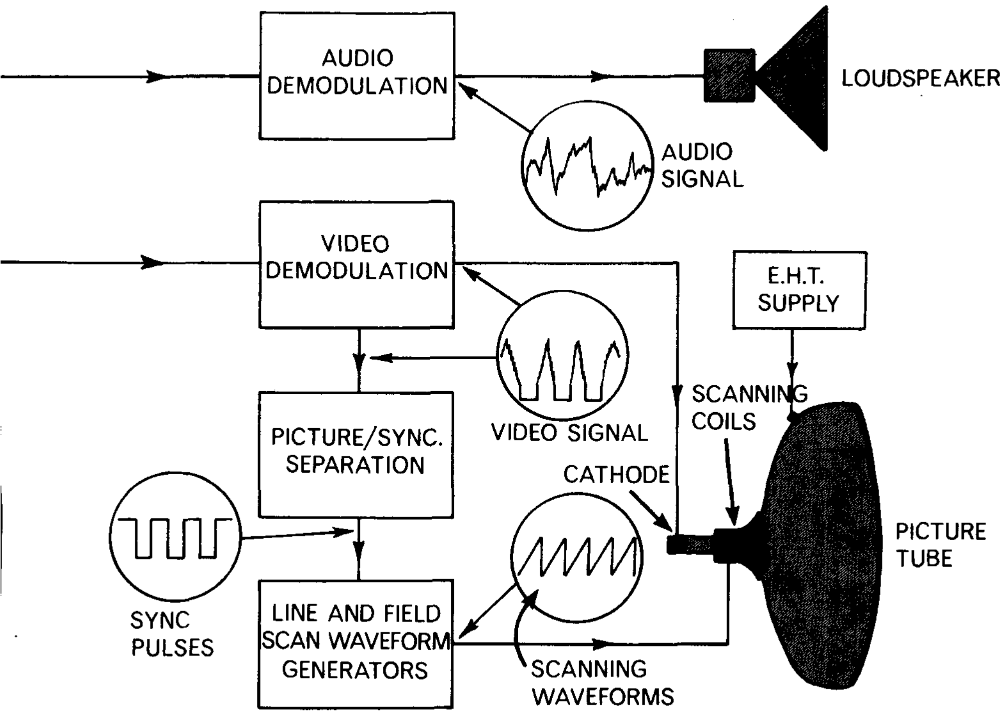
The essential differences between them are that the TV receiver normally operates at frequencies not used for the domestic radio receiver, and that it contains additional circuits devoted to reproducing the picture on the picture tube, to generating timebases for the line and field scans, and to synchronizing these timebases with those used in the TV cameras in the studio.

Note that the illustration above shows *only the essential links* in the process of achieving audible and visible reproduction of the studio scene. Many and great advances in receiver design have been achieved in the last 30 years. You will be learning about many of these improvements later on, and you will see that the performance of a TV receiver reduced to the essentials shown above would fall far below present-day standards of viewing.

Without these essentials, however, there would be no sound or picture at all.

Two different systems of television exist, as you know, side-by-side in Britain today.

The Essential Functions of a TV Receiver



The 405-line system operating in the VHF band of frequencies carries the programmes radiated by BBC 1 in Band 1, and by all stations of ITV in Band 3. It employs *positive* amplitude modulation of the carrier to produce its vision signal, and *amplitude modulation* for its sound carrier.

The 625-line system operating in the UHF frequency band carries the programmes put out by the BBC and the Independent Television companies in Bands 4 and 5. It employs *negative* amplitude modulation to produce its vision signal, and *frequency modulation* for its sound carrier.

Since it appears likely that both of these systems will co-exist in the British air for a good many years to come, the type of receiver studied in this book will be the so-called **Dual-Standard Set.** These sets consist effectively of a complete 405-line receiver linked to a complete 625-line receiver inside the same set, but with both receivers using common circuits and components wherever possible. Since the two receivers work on different line structures and employ different modulation techniques, a complex switching arrangement is involved every time the viewer changes from one system to the other.

The principles on which the 405-line system operates follow on directly from what you learnt in *Basic Electronics*, so the circuit arrangements of that system will generally be treated first in the pages which follow.

The Pattern of the Series

In the remainder of this Section, the circuit arrangements of a dual-standard TV receiver will be built up in block schematic form. These blocks will then be put together to make up the complete receiver shown (still in block diagram form) in the large double-page illustration on pages 2.14 and 2.15.

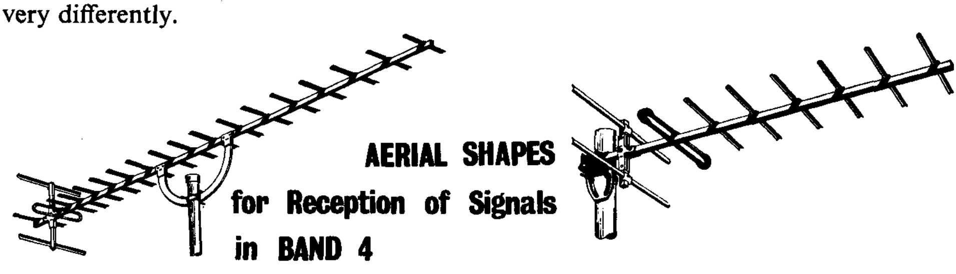
Later Sections will consider each of these blocks in greater detail; and the series will conclude with a short Section on fault-finding in TV receivers.

Essential Components of the TV Receiver—The Aerial

The starting point in the reproduction process is, of course, the **aerial**; for it is here that the wanted signal is collected from the air before being applied to the receiver proper.

You already know that aerials designed to pick up signals lying within different wavebands are of completely different shapes. For some 20 years or so past, the urban skyline of Britain has been festooned with the familiar designs erected to pick up the Band 1 programmes of the BBC.

Such aerials as these would have a poor response, however, to signals whose frequencies lay (for instance) in Band 4, between 470 and 582 MHz. That is why aerials designed to pick up Band 4 and Band 5 programmes are typically shaped very differently.



Aerial arrays can be designed to respond much better when they are pointed in one direction rather than in another. When such a *directional* array is properly mounted on the viewer's roof, its degree of selectivity towards the wanted signal will be much improved. You will learn more about the properties of aerials in Section 10.

All these different aerial shapes have been worked out over the years, both theoretically and by a continuing process of trial and error. It is an interesting fact, however, that whatever their shape, all aerials contain (for a given signal strength) almost the same total length of metal tubing exposed to the air. Thus although a Band 4 aerial looks much smaller and more compact than a Band 1 aerial, both are in fact presenting about the same overall length of sensitive antenna to the incoming signal.

Essential Components of the TV Receiver—The Tuner

The next stage in the handling of the signal detected by the aerial is the so-called **tuner** section, which is physically situated inside the receiver itself. Signals reach the tuner from the aerial through a coaxial cable. The internal impedances of aerial and tuner need to be carefully matched in order to keep attenuation of signal strength to a minimum.

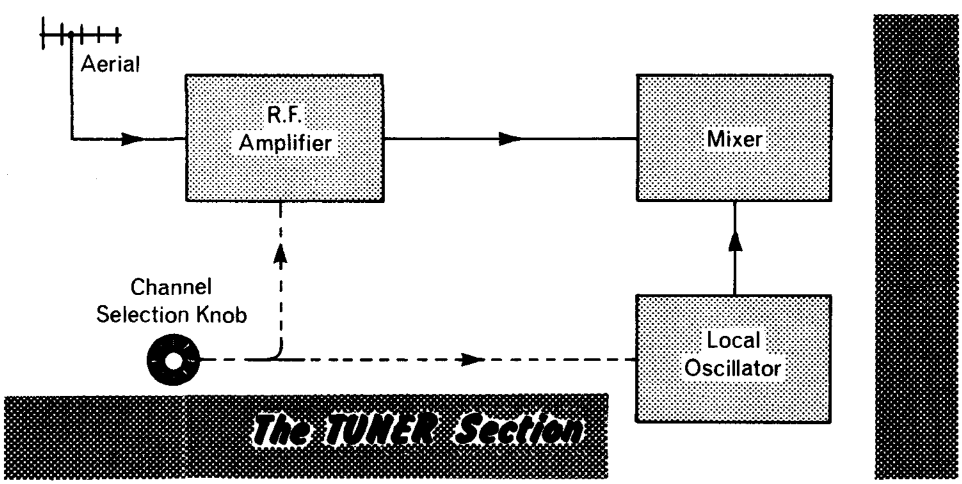
The function of the tuner is to pick out from the range of channels selected by the aerial the particular sound and vision signals required by the viewer, and to amplify them to a usable level.

Much further amplification will be required in later stages, however, and signals of the very high frequencies used in TV cannot in practice be satisfactorily amplified to the necessary levels without endangering signal stability. The second function of the tuner is therefore to lower the frequencies of the received sound and vision signals to *intermediate frequencies*, exactly as you saw being done to radio signals in Part 5 of *Basic Electronics*. The same superheterodyne principle is used as you there studied. The received signals are fed into a **mixer stage** together with signals from a local oscillator, whose frequency is constant and somewhat above the frequency of the received signals. There emerge two *different and still separate frequencies* (vision and sound respectively) as the joint output of the tuner section.

The very high frequencies handled in the tuner section create some special problems which make it necessary for the section to be carefully *screened*, both from the aerial and from the rest of the circuits in the receiver. It is even necessary for the several circuits inside the tuner itself to be screened from one another. You will see how this screening is done in Section 11.

The viewer selects the channel whose programme he wants to watch by operating a **channel selection knob** situated on the outside of the receiver casing, either on its face or on one of its side panels. Operation of this knob alters the settings (and consequently the values) of certain components contained in the **r.f. amplifier**. It also varies the frequency of the local oscillator so that the tuner as a whole shall respond to the frequency of a signal in a different channel.

The basic layout of the tuner section is shown below.



Essential Components of the TV Receiver—The IF Amplifiers

On leaving the tuner, the sound and vision i.f. signals pass on together towards intermediate-frequency amplification. The function of this **i.f. amplifier** section is to amplify the signals fed in from the tuner until they are large enough to be handled effectively in later sections.

At this point, there arises an immediate difference between the two systems which are combined in the Dual-Standard Set. This difference is so important that the opposite page has been devoted to a highly non-technical cartoon which may help you to get the essence of the matter firmly into your memory.

In this illustration the briefcases which the little matchstick-men are carrying to the appropriate i.f. amplifiers represent the respective i.f. carriers, and contain within them the modulations representing the sound and video messages. When the briefcases emerge, considerably enlarged, from the i.f. amplifiers, they are taken to the appropriate sound and vision detectors, where they are opened up and their contents are inspected.

If (as is possible) you have a mind which does not react happily to that sort of pictorial stimulus, here is the nub of the distinction in words.

IN THE VHF (405-LINE) SYSTEM

There are *separate* amplifiers for the sound and vision i.f. signals. It is therefore necessary to separate the two signals before the full i.f. amplification is applied to either of them.

IN THE UHF (625-LINE) SYSTEM

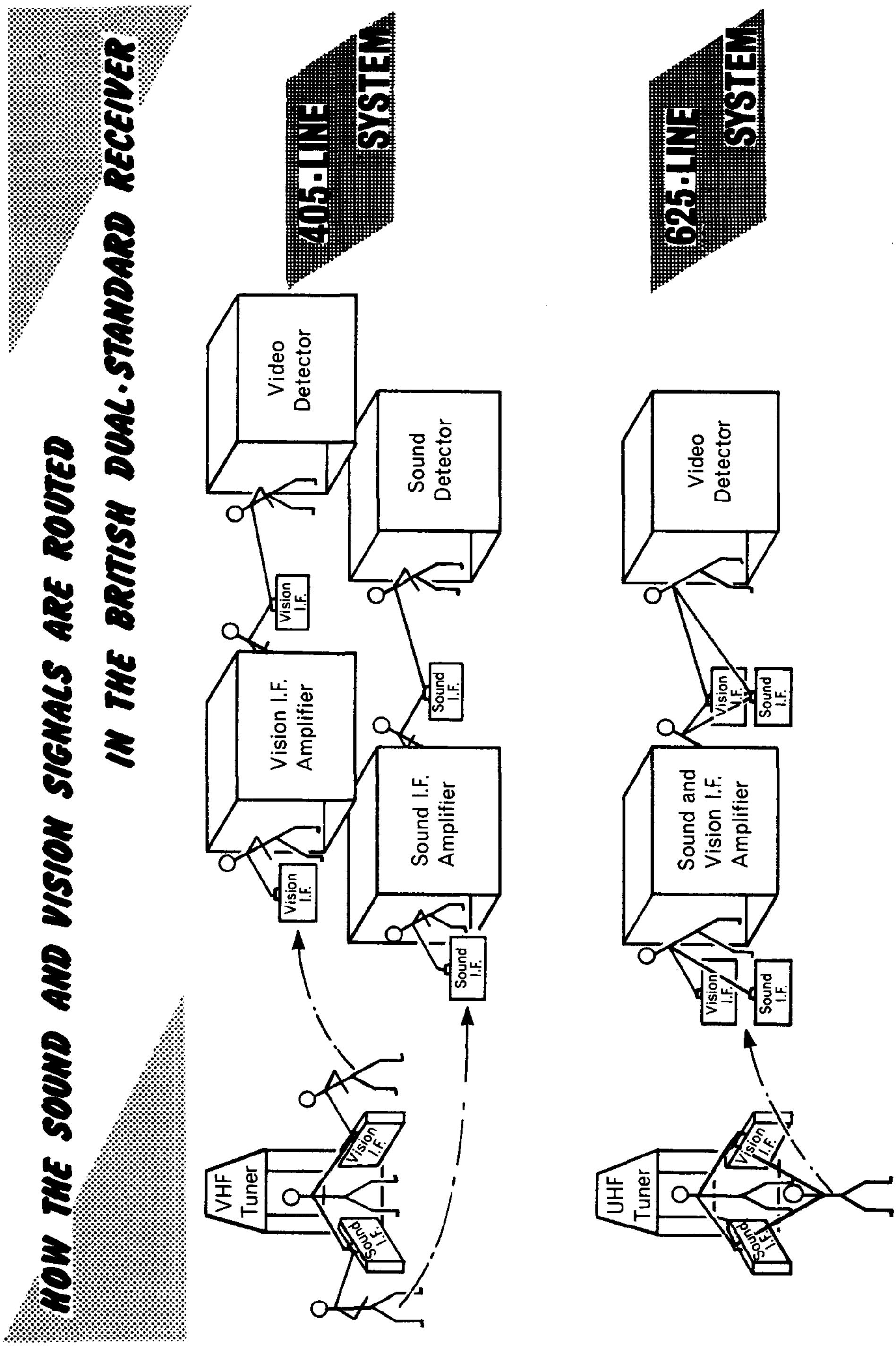
Both sound and vision i.f. signals are put through a *common* i.f. amplifier, before being separated at a later stage in the receiver.

Manufacturers' practice varies about the way in which the sound and vision signals in the 405-line system are separated from one another before being fed to their respective i.f. amplifiers. Sometimes the signals are separated as soon as they leave the tuner, by being passed through a *filter*. This consists generally of a series-tuned circuit offering a much lower impedance to one of the signals than it does to the other, so enabling the two signals to be routed in different directions. Sometimes separation of the signals is accomplished in this way only after some degree of i.f. amplification has been applied to both of them.

Amplification of both signals in the 405-line system is achieved in accordance with the general principles you learnt about in Part 5 of *Basic Electronics*. The separated sound and vision signals reach their respective i.f. amplifiers, where two things happen to them. Each is passed through a number of consecutive *amplifying* valves—generally not fewer than three of them. The anode circuit of each of these valves is tuned to resonate to the i.f. frequency of the signal it is handling—but much more sharply so tuned than the circuits in the tuner itself could be. A second function of the i.f. amplifier in the 405-line system is thus to *increase the selectivity* of the receiver as a whole.

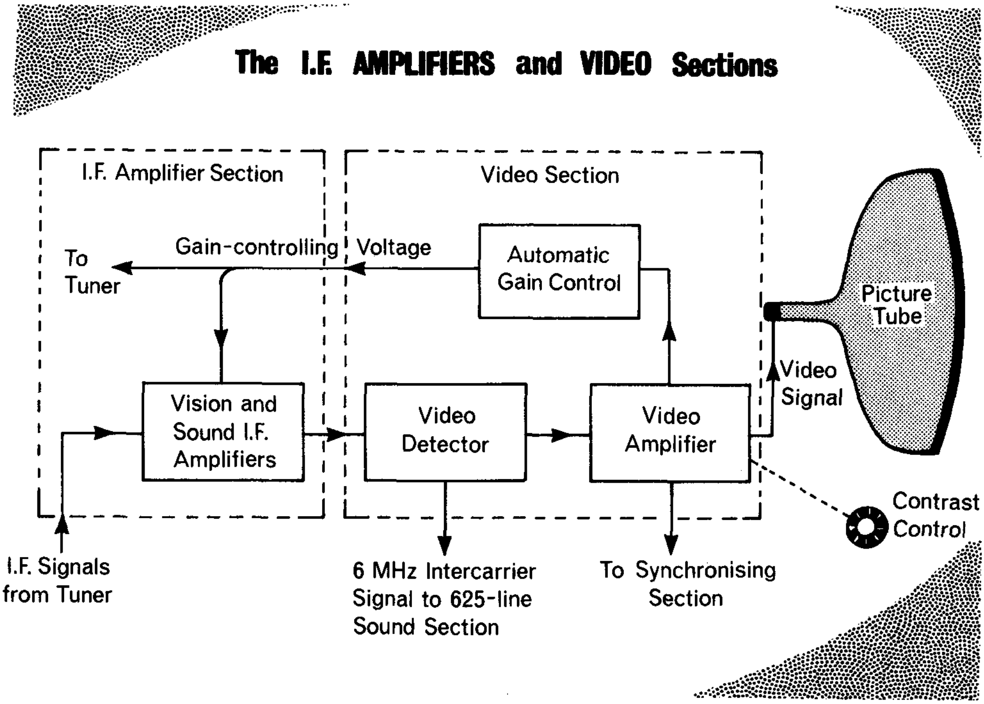
In the UHF (625-line) system, the sound and vision signals are amplified together in a series of similar stages, and are passed on (still unseparated) to the next section.

Routing the Sound and Vision Signals



Essential Components of the TV Receiver—The Video Section

The video section of all TV receivers consists essentially of three stages—the **video detector**, the **video amplifier** and an **automatic gain control** (AGC) circuit.



The task of the *video detector* is to remove from the vision carrier the video modulation carrying the picture information, and to pass this information to the *video amplifier*. After amplification in that stage, the video signal is applied to the cathode of the picture tube, where it is used to modulate the intensity of the scanning beam in such a way as to build up the desired picture on the screen.

In the 405-line system, in which the sound signal never reaches the video stage at all, this process is quite easy to follow; but a complication arises in the 625-line system, in which (you will remember) the sound and vision signals are at this stage not yet separated. You must now pause a moment to see how this separation is achieved.

The UHF vision signal, you will recall, is amplitude-modulated and has a steady frequency; the sound signal is frequency-modulated. When the two signals arrive together in the video detector, they are made to beat together in a mixing action, with the constant frequency of the vision signal acting as a kind of local oscillator beating with the varying frequency of the sound signal. The output is a difference frequency which you can simply calculate as 39·5 MHz (the frequency of the vision i.f. signal), *minus* 33·5 MHz (the frequency of the sound i.f. signal), *plus* and *minus* the comparatively small (75 kHz maximum) frequency variation of the sound signal. The difference frequency thus has a steady *mean* frequency of 6 MHz, which is being continuously modulated either side of 6 MHz by the frequency-modulated sound signal.

Essential Components of the TV Receiver—The Video Section (*continued*)

The 6 MHz beat-frequency signal you learnt about on the last page is commonly called the **intercarrier signal.** It needs now to be applied to the sound section of the receiver to be demodulated for extraction of the sound signal.

It is fed to this section *through the now-idle sound i.f. amplifier stage of the 405-line system*, and dealt with thereafter in the sound section of the receiver in a way you will read about in a moment. Note at this point that it is a feature of the British Dual-Standard set for stages in the system to which the receiver is *not* at a given moment switched to be used in the circuitry of the system to which the receiver at that moment *is* switched.

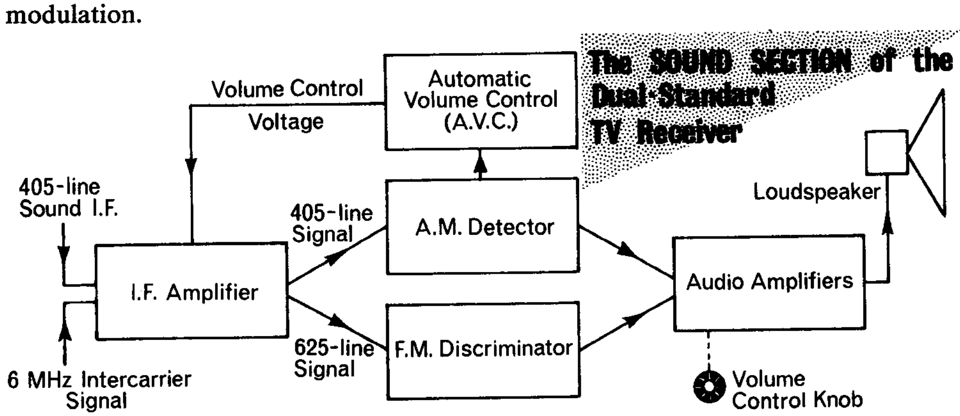
So much, for the present, for the video detector. From the *video amplifier* there are taken two other outputs in addition to the video signal. The first serves, in both systems, as input to the first stage of the *synchronizing section*, of which more below. The second is a voltage applied to an **AGC circuit**, which works somewhat differently in the two systems. In the 405-line system, the AGC voltage is fed back *both* to the vision i.f. amplifier *and* to the VHF tuner. In the 625-line system, it is applied to the vision i.f. amplifier only. Wherever it is applied, its purpose is the same—to try to maintain at a constant level the overall gain of the vision circuits of the receiver, whatever the strength of the received signal. The object is to prevent the frequent sudden and inevitable increases and decreases in signal strength from showing up as irritating brightenings and dimmings of the picture on the screen.

The AGC circuit does its job by producing a negative feedback voltage of appropriate value, which varies the bias conditions (and therefore the gain) of the valves to which it is applied.

Only one other feature of the video section remains to be mentioned at this stage. The **contrast control knob** is situated on the outside of the receiver (on its front or on a side panel), and is manipulated by the viewer to vary the amplitude of the video signal applied to the cathode of the picture tube, and so the degree of *picture contrast* (that is, the ratio of "blackness" to "whiteness" on the screen).

Essential Components of the TV Receiver—The Sound Section

The only complication in the sound section of the British Dual-Standard receiver arises from the fact that the VHF (405-line) system uses amplitude modulation to produce its sound signal, while the UHF (625-line system) employs frequency modulation.



Essential Components of the TV Receiver—The Sound Section (*continued*)

The process of AM detection was described in Part 5 of *Basic Electronics*, that of FM detection in Part 6 of the same Series. There is no point in repeating the two accounts in detail here. The *VHF signal* arrives from the VHF tuner and the sound i.f. amplifiers direct. In the AM detector block it is demodulated, in exactly the same way as it was in the superhet radio receiver you studied in Part 5. The Automatic Gain Control circuit was described in *Basic Electronics*, and performs the function of keeping the receiver output reasonably constant despite variations in the strengh of the received signal.

In the UHF system, the 6 MHz intercarrier from the vision detector arrives in the sound section via the sound i.f. amplifiers of the VHF system (which, you will recall, the UHF system in the Dual-Standard Receiver "borrows" for the occasion). This intercarrier, however, is carrying both the amplitude modulation which is required in the vision section and the frequency modulation which is required in the sound section. It is therefore passed first through a *limiter circuit* (such as you can study in detail in Part 1 of *Basic Electronic Circuits*) where it is "clipped" of all variations in amplitude so that the signal emerging is one varying in frequency only.

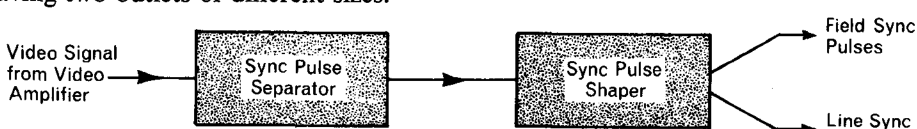
The FM output of the limiter is then converted to an audio signal in a *discriminator circuit* such as you read about in Section 3 of *Basic Electronics*, Part 6. The frequency of this audio signal is the frequency at which the deviation of the FM signal occurs. Its amplitude varies with the magnitude of this frequency deviation.

Both audio signals, *VHF and UHF alike*, are then amplified in a *sound power amplification* section common to both systems, and are routed to the diaphragm of the loudspeaker. The audio level of the loudspeaker output is controlled in the usual way by means of a *volume control knob* such as you have manipulated many times on the front panels of your own TV or radio sets.

Essential Components of the TV Receiver—The Sync Section

You will recall that the video amplifier in the video section of the receiver has a third output (in addition to its outputs to the AGC circuits of both systems and to the cathode of the picture tube).

This third output is applied to the synchronising section—and you will be relieved to learn that from this point on there are no differences of principle in the way in which the two systems in the Dual-Standard Set operate. The signal entering the sync section is no different from the video signal applied to the cathode of the picture tube. This latter signal is simply divided up so as to flow, in unequal proportions, to the two sections—rather as if it were water flowing down a pipe to a tap connection having two outlets of different sizes.



The SYNC SECTION

The function of the sync section is to separate out the sync pulses from the picture-signal content of the video signal. It then sorts out the *line* sync pulses from the *field* sync pulses, and converts them into waveforms capable of synchronising the oscillators of the *line and field scan generators.*

Essential Components of the TV Receiver—The Sync Section *(continued)*

The separation of the sync pulses from the picture signal is achieved with the aid of a simple limiter circuit (*Basic Electronic Circuits*, page 1.48). Separation of the line and field sync pulses from one another calls for the use of integrating and differentiating circuits of the type you will most easily recall by referring to *Basic Electronic Circuits*, page 1.44.

After they have been separated, both line and field sync pulses are put through separate amplitude-shaping circuits (*Basic Electronic Circuits*, Section 11) whose function is to "square up", or make more nearly vertical, the leading edges of the two pulse trains. The line and field scans both need to be triggered off at very exact moments of time, and this can only be done with sufficient accuracy if the trigger pulses have sharply-defined leading edges.

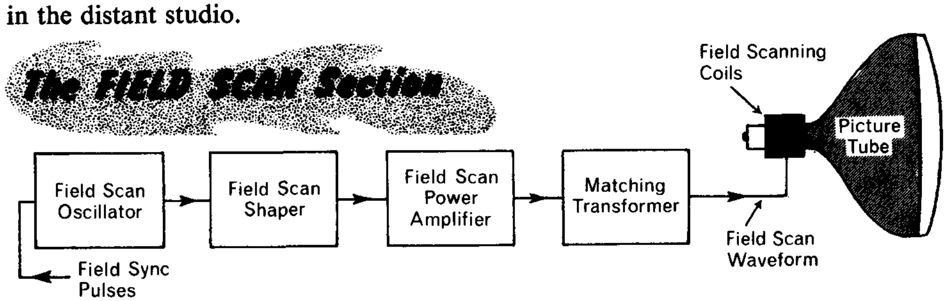
Essential Components of the TV Receiver—The Field Scan Section

In both systems in the Dual-Standard Set, the function of this section is to produce a waveform which is capable of causing the scanning beam of the picture tube to complete one vertical scan of the tube fifty times in every second.

The scanning waveform itself is a linear rise or fall of voltage or current, such as a sawtooth (*Basic Electronic Circuits*, Part 2). Such a waveform, you there learnt, is capable of producing on the screen an accurate *timebase* on to which the information contained in the picture signal can be superimposed. Nearly all TV picture tubes employ the electromagnetic method of deflecting the electron beam down and across the face of the tube. This necessitates (*Basic Electronic Circuits*, Part 2 again) the application of a linearly rising or falling *current* to the deflection coils of the tube.

The scanning waveform typically starts life as a reasonably square wave of voltage generated by an oscillator such as a multivibrator, *oscillating at exactly 50 cycles per second* (50 Hz). This is, as you know, the field scanning frequency.

The oscillation is kept precisely at 50 Hz by the field sync pulse which is applied to it from the preceding sync section. You will remember that this sync pulse was itself applied to the transmitted signal by a similar oscillator working in the camera circuits many miles away. Remembering the enormous speed at which radio waves travel, you can now see how the apparent miracle is achieved of exactly synchronising the appearance of the televised picture on the screen of your set with the scan of the scene in the distant studio.



The 50 Hz square wave of voltage is next passed through a shaping circuit, which re-shapes it as a sawtooth having a good linear rise (or fall). It is then sent on its way through the *field scan power amplifier* towards the *field scan coils* fitted round the neck of the picture tube.

Essential Components of the TV Receiver—The Field Scan Section (*continued*)

A difficulty arises, however, because the output of the field scan amplifier valve has a high impedance, while the field scanning coils of the tube have a very low one. In order to match these two Z's and so to ensure maximum transfer of energy to the coil, a *matching transformer* is inserted between the amplifier and the coil.

This transformer is of the step-down variety, having many turns in its primary and few turns in its secondary. It is therefore capable of stepping down the voltage, and stepping up the current, to the desired level. (Exactly the same type of transformer is needed, as you will recall from *Basic Electronics*, Part 5, between the final amplifier of the ordinary radio receiver and the loudspeaker.)

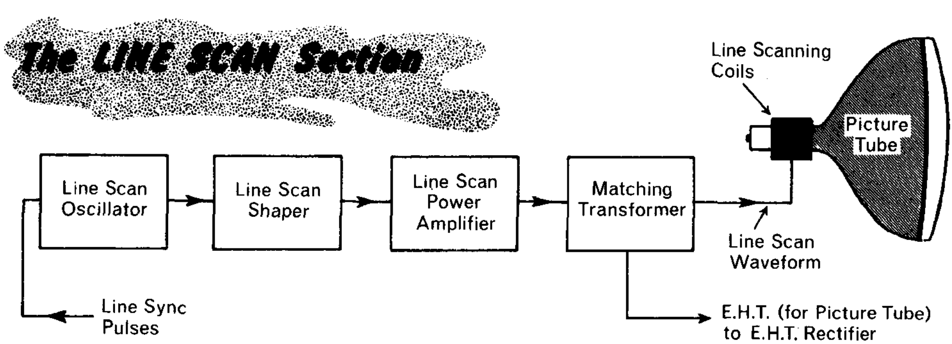
Essential Components of the TV Receiver—The Line Scan Section

The function of this section is to produce a waveform which is capable of causing the scanning beam of the picture tube to move across the screen at the rate appropriate to the system. In the 405-line system, this rate is **202½** horizontal scans during the period of every field scan. (Remember the effects of interlacing, with every line of the tube scanned *once in every second field scan.* Half 405 is 202½.)

Similarly in the UHF system, the rate of line scan needs to be half 625, or **312½**, horizontal line scans during the period of every field scan. If you bear in mind that "the period of every field scan" is only one-fiftieth of a second, and that two or three hundred-odd line scans have to be accomplished within this period, you will get some idea of the enormous speed at which the scanning beam has to move. It can only hope to scan at this speed because (you will remember) an electron beam has virtually no momentum.

The line scan waveform, like its field scan counterpart, is generated in an oscillator of one kind or another (different makers differ in their choice); but the frequency of oscillation must be enormously more rapid than it was in the field scan section. If the VHF scanning beam has to complete 202½ line scans in one-fiftieth of a second, its frequency needs to be $202\frac{1}{2} \div \frac{1}{50}$ cycles per second, or **10·125 kHz.** By a similar calculation, the frequency of the 625-line oscillator needs to be **15·625 kHz.**

In exactly the same way as in the field scan section, the line scan oscillator is synchronized with the corresponding oscillator working in the distant camera circuits. The synchronized waveform is then passed in turn through an amplifier to "beef it up" and through a matching transformer to "step it down", before being applied to the line scan coils fitted round the neck of the picture tube.



Essential Components of the TV Receiver—Power Supplies

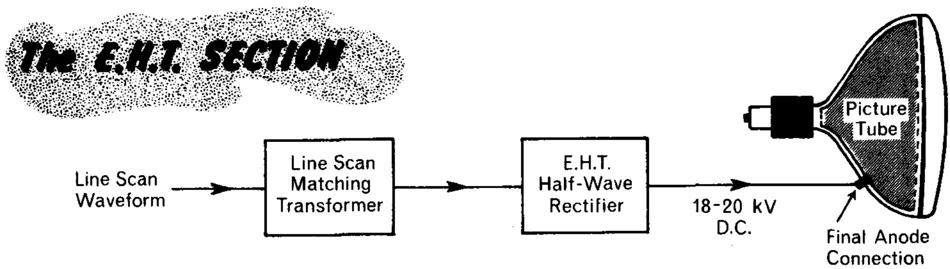
Both the VHF and UHF systems in the British Dual-Standard Receiver have need of two different kinds of power supply.

(*a*) *The EHT Section*

The job of this section is to produce the very high voltage needed at the final anode of the picture tube to draw the electron beam from the cathode of the tube to the screen. In a 23-inch tube, this voltage needs to be of the order of 18 to 20 kilovolts.

Although the current carried is only a small one, a voltage of this order is obviously dangerous; so remember to keep your fingers away from the final anode connection of the picture tube whenever your TV set is switched on.

The voltage required is generated in the matching transformer in the line scan section of the receiver. This transformer is actually an auto-transformer consisting of thousands of turns of wire. It is tapped at various points for connection to the line scan power amplifier and to the scanning coils. When the current to the picture tube falls away very rapidly during the fast fly-back period of the scan, a very high back-e.m.f. is induced across the auto-transformer.



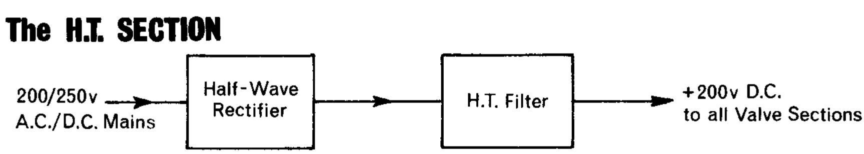
The a.c. voltage induced in the transformer during flyback is first applied to an ordinary *half-wave rectifier* circuit to turn it into d.c. The d.c. is then applied as an electron accelerator to the final anode of the picture tube.

This method is used in all TV receivers, and is known as the *flyback-derived* type of EHT generation.

(*b*) *The HT Section*

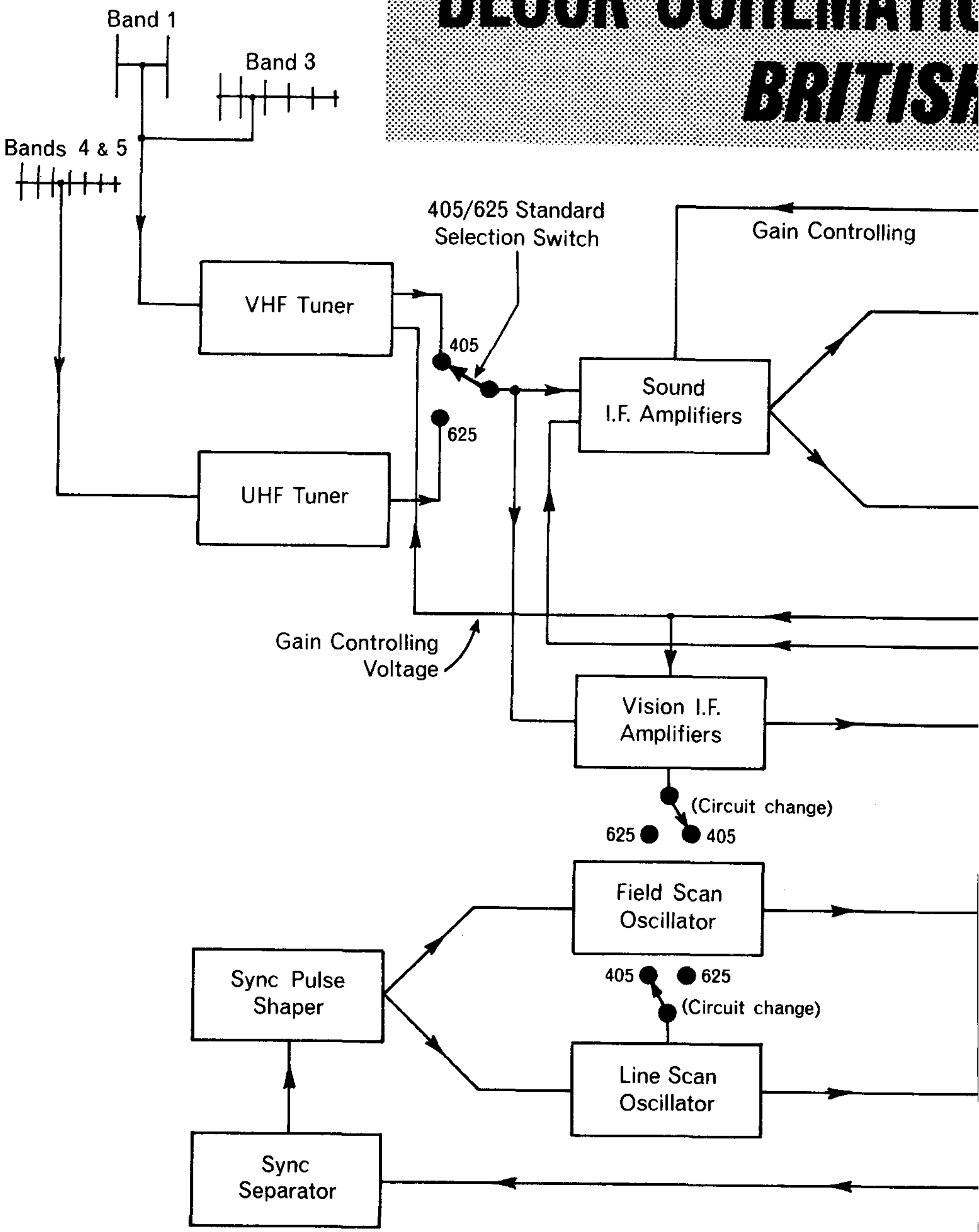
All the valves in a TV receiver need a heater supply for their cathodes, and the usual HT supply to enable them to operate.

This HT is derived from a section of the receiver which has been omitted from the block schematic of the Dual-Standard Set on the next two pages in order not to over-complicate the diagram. It is taken direct (*i.e.*, without transformer action) from the mains supply, and (after rectification) is normally of the order of +200 volts. It is then passed through the simple line of circuitry shown below.

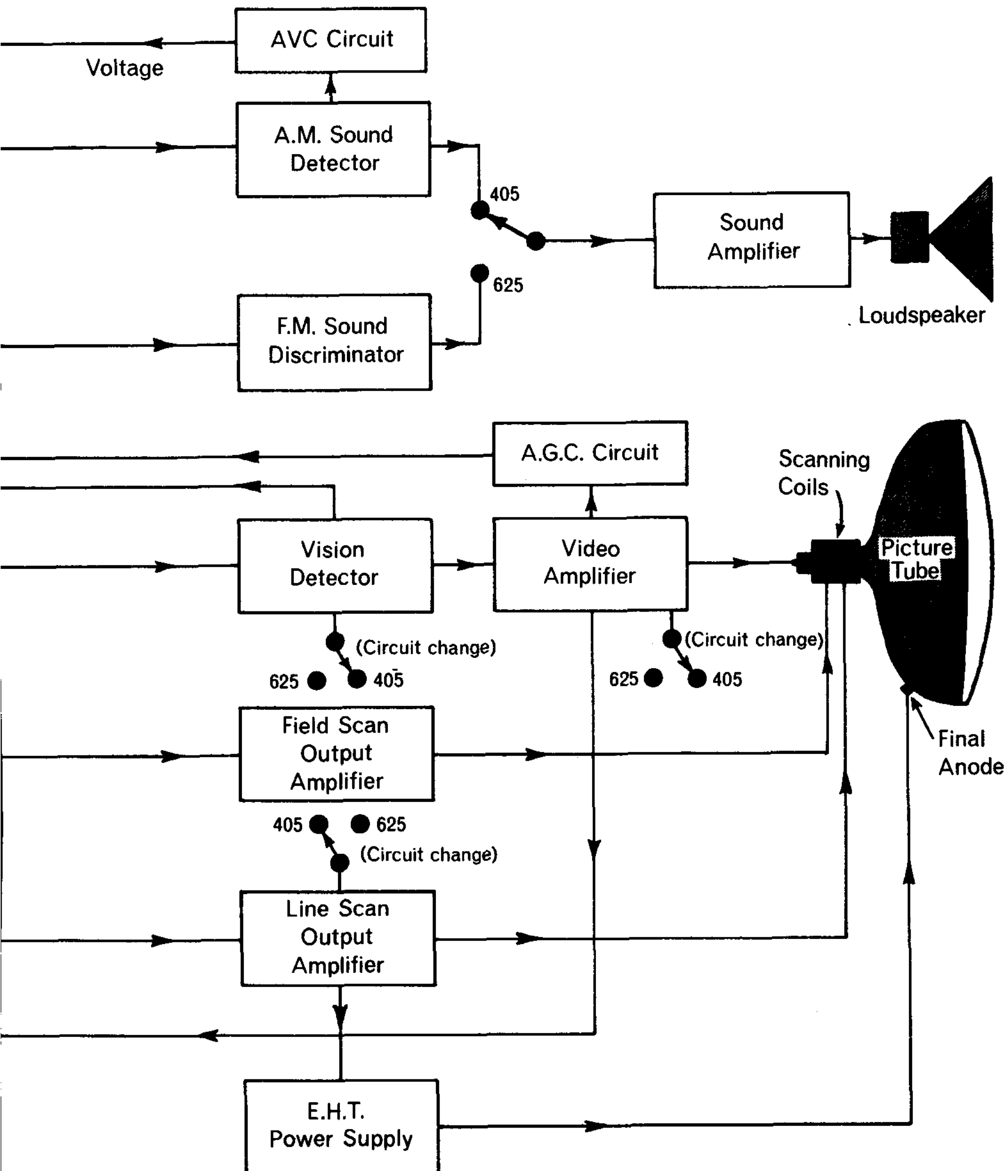


BLOCK SCHEMATI

BRITIS



f the DUAL-STANDARD TV RECEIVER



Essential Components of the TV Receiver—Power Supplies (*continued*)

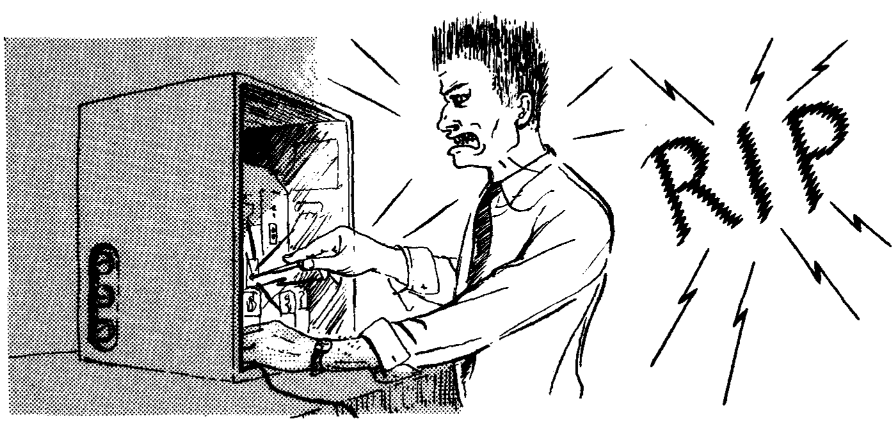
In the HT section, the a.c. from the mains is first rectified by being passed through a normal half-wave rectifier circuit. The d.c. output from this circuit is then smoothed (that is to say, it has the ripples taken out of it) by being applied to an *HT filter circuit*, which uses either the *LC* or (more usually) the *RC* smoothing techniques you learnt about in Section 6 of *Basic Electronics*, Part 1.

WARNING

Remember always that the HT supply at any point in a TV set is capable of delivering a much higher current than is the EHT supply, despite the latter's much higher voltage. So whereas a shock from the EHT can give you a nasty burn, current from the HT supply can kill you. For this reason, it requires considerable experience before you can safely fiddle about anywhere in the circuitry of a TV set once it is switched on. YOU HAVE BEEN WARNED!

Whatever the degree of your experience, the following rules for exploring the inside of a live TV set should always be observed:

1. **Never do it with wet hands. Water conducts current far better than does dry skin.**
2. **Always see that the handle of any tool you intend to use is properly insulated, and not broken or cracked. To patch up a split handle with insulating tape may work all right for a long time, but—is it really worth the risk?**
3. **Rubber is a useful insulator. It is safer to wear rubber-soled shoes, and to stand on a dry rubber mat. Even if you haven't got such a mat handy, do at least see that the surface you stand on is *dry*.**
4. **Keep your left hand in your trouser pocket all the time you are poking about inside the set with your right hand. If you do this, any current you may pick up will flow to earth down the *right-hand* side of your body. Most people keep their heart on the left.**
5. **The most hazardous posture you can possibly adopt is in some respects the most convenient. But if you are probing away with your right hand in the set, with your left hand resting anywhere on the chassis, you are guaranteeing that any current you may pick up will take the most dangerous possible path on its way to earth through your body.**



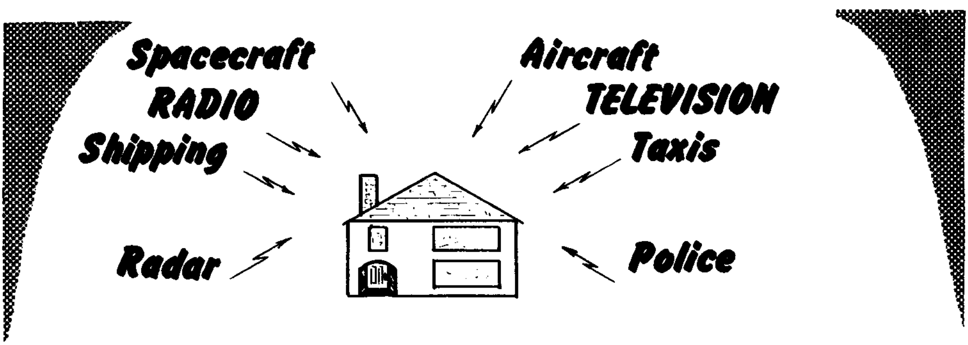
§10: THE RECEIVING AERIAL

In a technically advanced country like Britain, the air is everywhere filled—indoors and out-of-doors, in bedrooms, bathrooms, churches, trains and in the depths of the countryside—with thousands upon thousands of man-made electromagnetic waves of varied origin and many different kinds.

All of these waves (which can be neither seen, felt nor heard by an unaided human being) have been propagated in order to convey intelligence of one sort or another between two or more distant points. These messages are all present in the air together, some of the signals being very strong but many so faint as to be barely capable of detection. The carrier waves on which the signals travel vary greatly in wavelength.

The import of the intelligence carried varies no less widely than the amplitude of the signals and the frequency of the carriers—ranging from landing instructions for a jet airliner coming in from Sydney or Capetown to the return echo of a radar beam bounced off the Moon, a Z-car message to a police patrol, or the sound-and-vision record of an athletics meeting in Russia travelling to New York via a satellite permanently stationed 2,000 miles above the middle of the Atlantic.

Aircraft, shipping, military vehicles, radar, spacecraft, navigation aids, radio and television broadcasting—all contribute to the vast communications network which now encircles the globe. But of all these signals the most numerous and the most powerful are those which emanate from the various national radio and TV broadcasting stations; and it is they alone which are the concern of this book.



Designed to reach millions of listeners and viewers in their country of origin (and often in other countries as well), most radio and TV signals are extremely powerful. Yet there are a great many of them; they travel on very different frequencies; and even a strong signal can fade to low power in an area in which it may be important for it to be picked up. The receiving aerial must therefore be capable of *very accurate selection* among the multitude of signals impinging on it. It must be able to reject (or, rather, to remain indifferent to) the vast majority of them; but it must respond at once to the wanted signal, however faint it may be at the point of reception.

You will not be surprised to learn that, with this sort of task to perform, the aerial of a TV receiving set is a more complicated object than a glance at the serried ranks of them rising above any street in urban Britain might lead you to suppose.

The Requirements of a TV Aerial

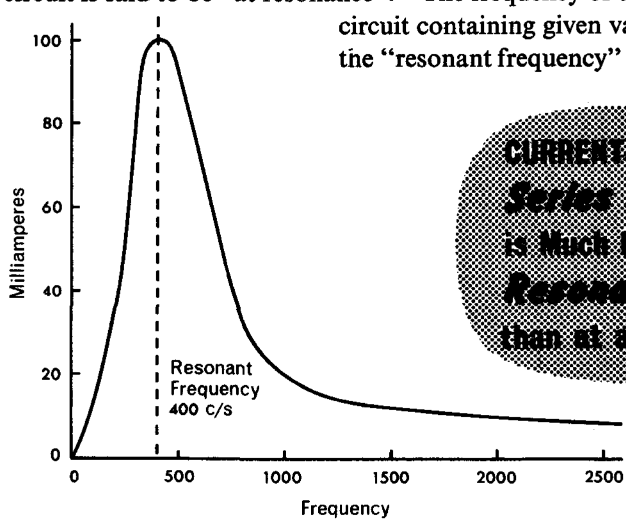
The task of a TV receiving aerial is to extract from the sound and vision signals of the desired transmission the amount of energy required by the receiver to reproduce adequately the sounds and the visual scenes created in the studio. Since the strength of the wanted signals varies so widely in different parts of the country, large and complicated aerials are needed to perform this function in areas of poor signal strength, while quite simple ones suffice in areas of good signal strength.

The aerial performs its task by responding to *signal frequency*. It responds well to the frequencies of the two wanted (sound and vision) frequencies, but very poorly to signals of other frequencies. To be rather more precise, the aerial must be made to respond well to a *narrow range of frequencies in a given channel in a given Band.*

In Britain, as you know, the sound and vision signals of a given transmission are contained in frequency channels either 5 MHz wide (in the 405-line system) or 8 MHz wide (in the 625-line system). The ideal aerial is therefore one whose frequency response, or bandwidth, is just wide enough to accept the range of frequencies contained in a single channel, and to reject all other frequencies. In practice, however, as you will see, it is sometimes necessary for the aerial to be made to respond to a *group of channels* rather than to a single channel only.

The principle on which any receiving aerial works is that, when the electromagnetic waves radiated from the transmitter cut across the aerial, they generate in it a small voltage. This voltage causes to flow in the aerial system a weak current having the same frequency, and carrying the same modulations, as the current in the transmitter which caused the waves to be radiated in the first place. The problem is to design an aerial in which this induced current will be as large as possible when a signal in the desired frequency range cuts across it, and as low as possible when a signal of any other frequency arrives.

You learnt in *Basic Electricity*, Part 4, that when an alternating voltage is applied to a series circuit containing both inductance and capacitance (in addition, of course, to the normal R which any circuit contains), current flow is greatest when the inductive reactance (X_L) of the circuit is equal to its capacitive reactance (X_C), so that their effects cancel out. Circuit impedance is then minimum (equal to R only), and the circuit is said to be "at resonance". The frequency of the signal which causes a series circuit containing given values of L and C to resonate is the "resonant frequency" (f_r) of that circuit.



CURRENT-FLOW through a *Series Resonant Circuit* is Much Higher at the *Resonant Frequency* than at any other Frequency

The Requirements of a TV Aerial *(continued)*

What is needed for an efficient aerial, therefore, is something equivalent to a series resonant circuit in which the values of L and C are such that X_L and X_C will be equal when an alternating voltage of the frequency of the desired signal is applied to the circuit.

Such an equivalent is found in a length of hollow metal rod called a **dipole**, whose dimensions have been very carefully calculated.

The values of inductive and capacitive reactance which a dipole offers to an incoming signal of alternating frequency depend on several factors—notably the length and diameter of the rod, and (to a much lesser extent) the material of which it is made.

Aerial material is generally a compromise between good conductivity and reasonable cost, and the diameter of the aerial is largely dictated by another factor which you will learn about later on. This means that the amount of L and C in an aerial are principally dictated by its *length.*

How long, then, must an aerial be to do its job with maximum efficiency?

Imagine that you have a length of aerial rod to which you have connected an instrument capable of measuring the strength of a collected signal, and that this aerial is positioned, well clear of the ground and of other obstructions, in the field of a passing signal. Imagine also that you can slowly adjust the length of this aerial without disturbing its position.

You would find that as the aerial is slowly increased in length, so the signal collected by it increases correspondingly in strength. This is much what you would have expected, on the ground that the more there is of the aerial exposed to the passing wave, the more of that wave will it collect.

You would also find, however, that when the length of the aerial becomes equal to *one half-wavelength* of the signal being collected, the strength of the signal greatly increases; but then for a time actually declines as you slowly increase the length of the aerial still further. When aerial length approaches a further half-wavelength (making one complete wavelength in all), the collected signal again climbs to a maximum value, this time greater than it was with aerial length at half-wavelength. This sequence would, if other factors played no part, repeat itself for each additional half-wavelength increase in aerial length.

What is happening to the aerial to cause these fluctuating values of signal strength is that, whenever the aerial reaches the critical length of one half-wavelength (or any multiple of one half-wavelength) of the signal being received, it suddenly starts behaving like a series-resonant tuned circuit. X_C and X_L cancel out; minimum impedance is offered to the signal applied to the circuit; and the current flowing through the circuit rises to maximum value.

Now fix your expandable aerial to a length equal to one half-wavelength of a given signal, so that it resonates to that signal. As signals of other frequencies close to, but not at, the resonant frequency strike the aerial, X_C and X_L in the aerial begin to move out of balance with one another; and either inductive or capacitive reactance is added to the circuit as the frequency of the applied signal rises respectively above or below the f_r of the aerial. Current flow becomes smaller and smaller; and soon the impedance of the aerial circuit rises to a point at which incoming signals whose frequency is too far removed from the f_r of the aerial have great difficulty in getting through at all.

The Requirements of a TV Aerial *(continued)*

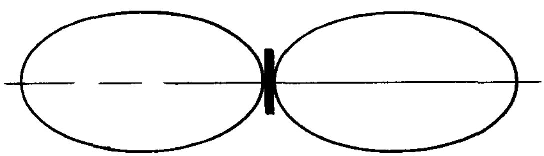
You have just seen that, provided its length remains an exact multiple of one half-wavelength of the required signal, the longer an aerial is, the better it is able to pick out this signal from the electromagnetic waves radiated by the transmitter. In practice, however, there are two good reasons why TV (and radio) aerials are seldom made longer than one half-wavelength of the required signal.

The first is a matter of practical convenience. You know that the wavelength, in metres, corresponding to any frequency is 300 divided by the frequency in question, expressed in megaHertz (MHz). The lowest frequency used in British TV is 41·5 MHz, which is the sound signal frequency in Channel 1. This corresponds to a wavelength of nearly 7 metres, or some 23 feet. An aerial of that order of size would be very difficult to handle, and to keep securely fixed on a wind-swept roof. Even at the top end of the VHF range in Band 3, the MHz divisor in the formula is still quite small, and all wavelengths in that range are still some metres long.

This practical limitation on aerial size does not, of course, arise in respect of transmissions radiated in the UHF bands. The frequencies there are so high that at the highest channel frequency (854 MHz) one wavelength is little more than 300 mm (12 inches) long. It would obviously be possible to construct and mount an aerial whose length is equal to quite a few of such wavelengths without serious difficulty. But now the second consideration arises.

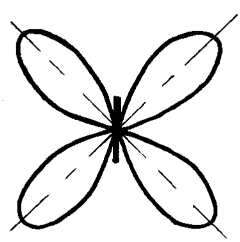
The polar diagram of a simple **half-wave dipole** mounted in free space is of such a shape that maximum reception occurs around its centre. That is to say, the reception pattern of a vertical dipole is predominantly horizontal. It consists of two lobes in the shape of the figure 8, as shown in the illustration below.

Half-Wave Dipole



For a *full-wave dipole*, however, the polar diagram is quite different. It consists of four lobes, none of them predominantly horizontal in orientation.

Full-Wave Dipole

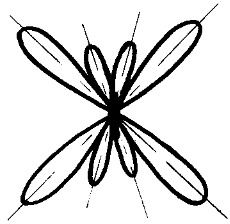


Maximum receptivity is obviously impossible with such an aerial, for the received signal can never be arriving from the direction in which all four lobes are aligned, at one and the same time. Even if one lobe could be pointed directly at the distant transmitter (which would seldom be very easy) the receptive power of the other three lobes would be entirely wasted.

The Requirements of a TV Aerial (*continued*)

The polar diagram of a *two-wavelength dipole* produces no improvement in receptivity. Although it has still more lobes, none of them is orientated towards the site of any likely transmitter, and again performance is apt to be poor.

Two-Wavelength Dipole



These lobes are really standing waves of received energy, and the reason why they make their appearance in the polar diagrams of the full-wave and two-wavelength dipole aerials is that part of the energy received by one half of the dipole is cancelled by energy of opposite phase present in the other half. This mutual cancellation of energy causes gaps where (in the half-wave dipole) there are lobes of energy, and lobes where there are gaps.

In certain applications (such as radar, for instance) it is often desirable to have energy radiated in a semi-vertical direction; and in these applications the full-wave or two-wavelength dipole is often used. For television purposes, however, the more horizontal polar diagram of the half-wave dipole is much more suitable.

Since, therefore, (*a*) the half-wave is the *minimum* length of dipole which will behave as a series-resonant circuit (and therefore the minimum length in which the first peak in the graph of collection efficiency will occur); and since (*b*) the half-wave is also the *maximum* length which presents an acceptable polar diagram, *the great majority of TV receiving aerials are constructed of a length equal to one-half of the wavelength of the signal which they are designed to receive.*

Two Practical Consequences.

Since aerial length plays so important a part in determining the range of frequencies which an aerial will efficiently accept, and since the length of a fixed aerial cannot easily be altered once it has been made, it follows that a given aerial will not necessarily be capable of accepting the same programme when it is taken to a different area of the same country. In the Reading area, for instance, the programmes of BBC 1 are broadcast on wavelengths of 7·23 and 6·6 metres in Channel 1 (that is to say, at sound and vision frequencies of, respectively, 41·5 and 45 MHz). In Birmingham, the same programmes are broadcast on wavelengths of 5·15 and 4·86 metres in Channel 4 (*i.e.*, at sound and vision frequencies of 58·25 and 61·75 MHz respectively.

A person moving house from Reading to Birmingham would therefore not be able to use his old Band 1 aerial in the new area, and might just as well leave it behind for the buyer of the house he is leaving.

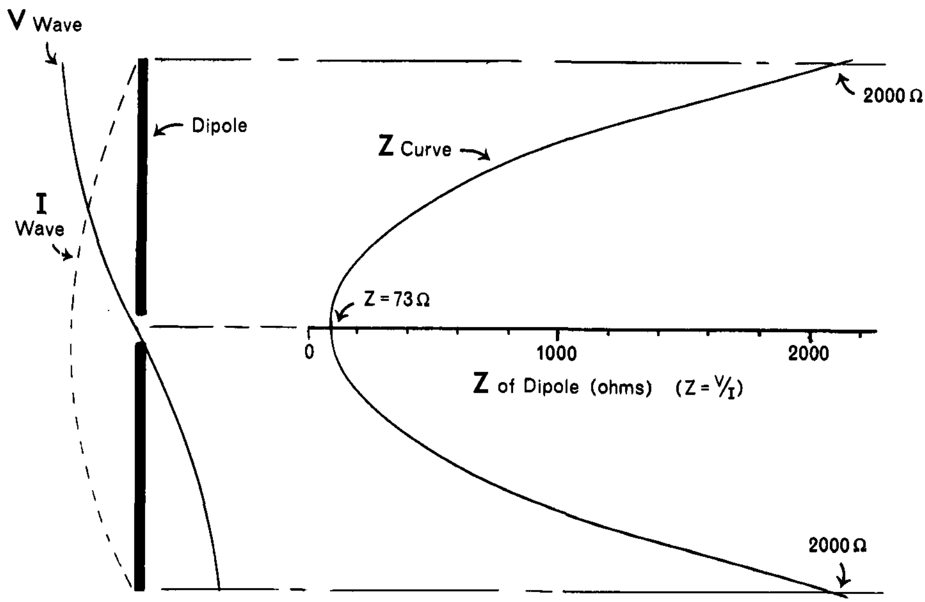
Another consequence of the inability of a given aerial to respond to more than a narrow range of frequencies is that aerials capable of receiving ITV programmes in Band 3, or BBC 2 programmes in Bands 4 and 5, need to be quite different from Band 1 aerials, and call for separate arrangements in the receiver itself to accept their very different signals.

Properties of the Half-Wave Dipole

A great deal of what you learnt about the properties of the half-wave dipole in Part 1 are equally true of the dipole when it is used in a receiving role. The main difference is that the transmitting dipole receives the signal from the transmitter in the form of a flow of current and radiates it as an electromagnetic wave, while in the receiving dipole an alternating voltage is *induced* by the arrival of the same electromagnetic wave. The principle is the same as that operating in a simple transformer, when a voltage is induced in the secondary winding (here, the dipole) by a voltage (here, the signal) generated in the primary.

The current which is made to flow in a half-wave dipole by the voltage induced in it by the signal varies at different points along the dipole's length because of the way in which the self-capacitance of the dipole is distributed. This capacitance is maximum at the *centre* of the dipole, so that a large charging current flows at that point, and minimum at the ends, where only a small charging current flows.

This distribution of current and voltage along a dipole remains constant irrespective of the strength of the signal. The distribution pattern shown in the illustration below is thus permanently valid. The heavy vertical line to the left represents a vertical dipole aerial. The voltage pattern along the aerial is shown in a thin unbroken black line marked *V Wave*, and the current pattern in a dotted line marked *I Wave.*



The Distribution of V, I and Z along the Half-Wave Dipole

The first important point to note about this pattern chart is that at the ends of the dipole voltage is maximum and current minimum; while *at the centre of the dipole current is maximum* and voltage minimum. Since the object to be achieved is that the wanted signal shall be the one which causes the largest current to flow into the aerial terminals, it is usual for an aerial to be tapped for its energy at its centre point.

Properties of the Half-Wave Dipole (*continued*)

The second important point to note about the illustration on the last page is that, since a half-wave dipole is a form of series-tuned circuit in which current flows under the impulse of alternating voltages, it must possess *impedance.*

This impedance varies at every point along the dipole. It is very high (several thousand ohms) at either end of the dipole, but falls to a minimum value (at about 73 ohms) at its centre. It can be calculated at any point along the length of the dipole by applying Ohm's Law to the instantaneous values of voltage and current at the desired point. That is how the curve of Z in the illustration on the last page was calculated.

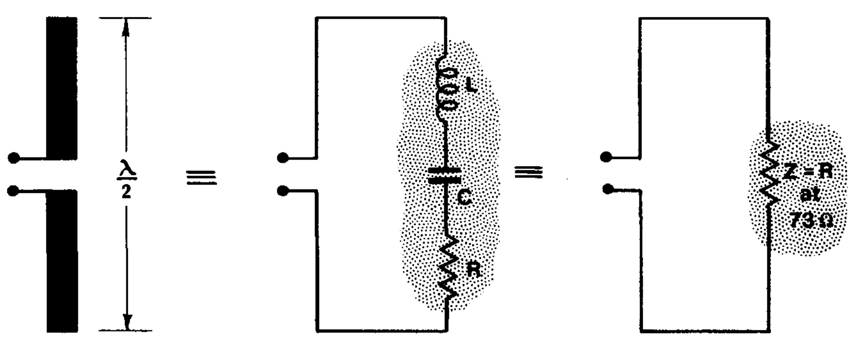
Provided that the ratio of dipole diameter to dipole length is kept very small, the value of impedance remains at the approximate value of 73 ohms at the centre of *any* half-wave dipole. This fact is of great importance, for it has led to the standardization of the characteristic impedance (Z_0) of much of the feeder cable which is used to take the signal from the aerial to the receiver.

You know from your work in *Basic Electronics*, page 4.48, that to obtain maximum transfer of signal strength this cable must have a Z_0 as nearly as possible equal to that which exists at the point of its junction with the dipole. Since most dipoles are centre-fed, the standard feeder cable used in Britain is manufactured with a Z_0 of some 73–75 ohms.

As you will see in the next few pages, there exist many devices for improving the reception efficiency of a dipole aerial; but most of them have the disadvantage of altering the impedance at its centre point. It is always expensive and sometimes inconvenient to use non-standardized cable. That is why efforts are always made, when any of these devices are used, to counteract their effect on the centre Z of the dipole, and to bring it back to the approximate value of 75 ohms.

The TV Aerial—Dipole Length

You have seen that the overall length of a half-wave dipole, measured from tip to tip, needs to be equal to one-half of the wavelength of the frequency to which the dipole behaves as a resonant circuit. At that length, the inductive and capacitive reactances of the dipole cancel out when the wanted signal arrives. Dipole resistance becomes purely resistive and therefore a minimum—at about 73 ohms.



The TV Aerial—Dipole Length *(continued)*

The statement that the overall length of a dipole needs to be equal to half the wavelength of the wanted signal must now be modified in two respects. Neither modification is of first importance in itself; but both help to show the complexities which exist in aerial design, and the need there is for compromise in solving them.

The first modification arises from the fact that all signals tend to travel slightly more slowly through the material of which an aerial is composed than they do through the atmosphere. This means that, to achieve perfect resonance, the correct length of the dipole needs to be *slightly less* than an exact half-wavelength of the required signal.

In practice, therefore, the length of a "half-wave" dipole is made about 0·48 times the wavelength of the signal to which it is to resonate. In more exact formula, the length of a dipole, in feet, can be calculated by dividing the number 468 by the frequency of the desired signal, in MHz.

The second modification arises out of the question, "What *is* the signal to whose frequency you want your aerial to resonate?" The TV aerial has to accept *two* signals, sound and vision, whose frequencies are some distance apart. The dipole cannot therefore be built to resonate exactly to both of them.

Some manufacturers solve this dilemma by cutting dipole length so that the aerial resonates exactly to the vision signal, as being the more important of the two; and are content to accept some attenuation of the sound signal in consequence.

Others adjust dipole length so that the aerial resonates to what is called a *centre frequency*. This is the geometric mean between the frequencies of the sound and vision signals. In the case of the BBC 1 transmissions in Channel 1, this centre frequency is about 43 MHz.

Geometric Mean of Sound and Vision Frequencies $= \sqrt{f_1 \times f_2} = \sqrt{41{\cdot}5 \times 45} \approx 43$ MHz

A frequency of 43 MHz corresponds to a wavelength of almost exactly 7 metres. Tip-to-tip length of this dipole is thus a little under 3·5 metres, and each of its two $\lambda/4$ sections measures nearly 1·75 metres, or about $5\frac{1}{2}$ feet.

A similar calculation for the ITV transmissions on Channel 9 of Band 3, whose centre frequency is about 193 MHz, shows that each quarter-wave section needs to be some 0·4 metres, or about 16 inches, long.

You will gather from these figures that the *overall length of dipole required decreases sharply as the operating frequency rises.* This obviously has its inconveniences, in that the higher-frequency signals tend to be weaker (other things being equal) than the lower-frequency ones, yet need to be detected by a smaller aerial. You will learn about some of the devices used to meet these inconveniences later on in this Section.

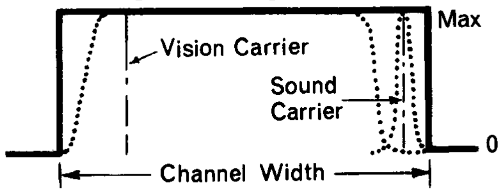
Meanwhile, it is of passing interest to note that if a half-wave dipole had to be designed to receive the BBC Light programme (sound only), which is broadcast at 200 kHz on a wavelength of 1,500 metres, the overall length of the dipole would need to be almost half-a-mile! That is why the use of dipole receiving aerials is usually confined to the h.f. and higher frequency bands—save in cases where convenience of installation must take second place to maximum efficiency.

The Frequency Response of a TV Aerial

You have seen that no dipole can be built to resonate exactly to the frequency of every signal it needs to pick up. What happens to the signal-collection efficiency of the aerial when it is "just off" resonance to the frequency of the desired signal?

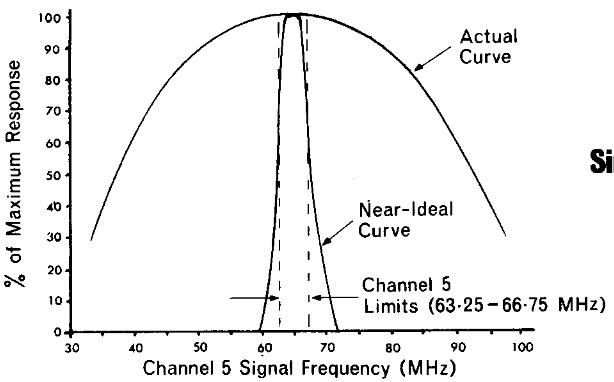
You already know that the *frequency response* of a receiving aerial expresses the degree to which the aerial will respond to signals of equal strength but varying frequency. It is generally displayed in the form of a graph. To a signal frequency corresponding to the resonant frequency of the aerial, response will always be maximum, and maximum current will be available at the aerial terminals to flow through the feeder cable to the first stage of the receiver itself.

Ideally, the frequency response of a TV aerial designated to operate in a single channel would be as you see it opposite—high and perfectly level to a range of signal frequencies covering the sound and vision signals and their two "outer" sidebands, zero to all frequencies lying outside these limits.



An *acceptance bandwidth* of this shape would ensure uniform receiver response to both sound and vision carriers and to their respective information-bearing sidebands, and would also ensure perfect rejection of all unwanted signals.

Unfortunately, a frequency response of this shape is not attainable in practice; and the response of a typical half-wave dipole is more like that shown below.



Frequency Response of a Single Half-Wave Dipole

This frequency response is reasonably flat at the peak of the curve, where it covers the range of frequencies contained in the channel, but the ability to reject unwanted signals outside that channel is not good. You will shortly see how the frequency response of a dipole can be materially sharpened by the addition of further elements to the aerial array.

It is also possible to *broaden* the frequency response of an aerial to cover several channels. This is not often desired at VHF, but one way of achieving it would be to increase the diameter of the rods of which the dipole is constructed. (Note, though, that this method affects the distribution of the internal impedances of the dipole, and so gives rise to matching difficulties with the feeder cable to the receiver.)

In UHF aerials, however, a broader frequency response is generally required. In Britain, these aerials are built to operate over all four of the channels on which it is planned eventually to radiate 625-line programmes. Since these channels are not contiguous, UHF aerials need to cover a frequency range of some 88 MHz. You will see how this is done by means of special aerial designs later on.

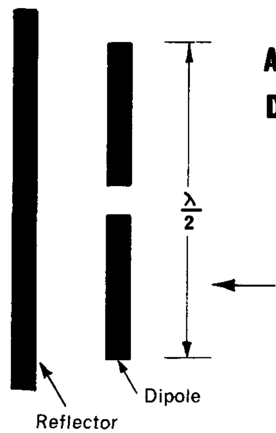
VHF Aerials—The Reflector

An ordinary dipole aerial, mounted vertically by itself in free space, would be very inefficient at its required task of detecting a particular signal coming from a known transmitter. The reason is that, mounted thus, it is what is called *omni-directional,* which means that it will receive signals with equal efficiency from any direction in the plane which lies at right angles to its own. It would therefore be liable to pick up interference signals of many kinds.

Ideally, of course, the receiving efficiency of an aerial would be zero in all directions save that from which the desired signal is arriving, and 100% in that direction alone. Although such an ideal cannot be realised in practice, excellent *directional* properties can be given to an aerial by positioning behind, and in front of, the dipole additional elements known respectively as *reflectors* and *directors.*

A **reflector** is a length of rod, usually a metal tube of the same diameter as the dipole but about 5% longer (so that it incidentally conforms rather closely to the exact half-wavelength which the dipole should theoretically measure). It is mounted in the same plane as the dipole, parallel to it, and *behind it with respect to the incoming signal.* The simplest example is the **H-aerial** with whose appearance you are very familiar.

The reflector is not connected electrically with the dipole, and is mounted at distances behind it which vary between one-tenth and one-quarter of the signal wavelength. This spacing is important, as you will see in a moment.



A Half-Wave Dipole Plus Reflector

The effect of a reflector is to re-radiate some of the energy of the wanted signal back to the dipole in such a way that it arrives there *in phase with* the signal itself, and thus adds to it. At the same time, any signal arriving from the rear of the dipole-reflector combination (*i.e.*, from a direction 180° away from the direction of the signal source) will be re-radiated by the reflector in such a way that the re-radiation reaches the dipole *in anti-phase with* the unwanted signal, and therefore diminishes its strength.

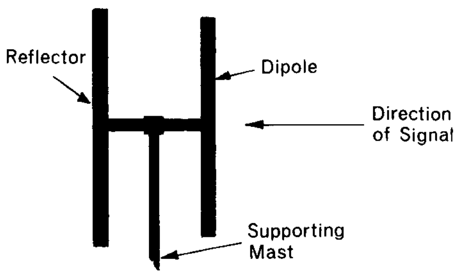
In other words, the presence of a reflector distorts the circular response pattern (or *radiation acceptance pattern*) of a solitary dipole into a pear-shaped lobe pointing towards the signal source, with a much smaller lobe pointing in the opposite direction (see illustration on page 2.28). It thus greatly improves the directivity of the dipole in the required (or *forward*) direction.

The addition of a reflector also *narrows the frequency response* of a half-wave dipole so that the combination tunes more sharply to the wanted signal. (This is equivalent to improving the selectivity of the resonant tuned circuit which is what the dipole aerial essentially is.) A disadvantage of adding a reflector to a dipole is that it tends, as you will see, to reduce the centre impedance of the dipole.

VHF Aerials—The Reflector (*continued*)

The degree of accentuation of a wanted signal reaching the dipole by means of an in-phase reflection from the reflector is termed the *power gain*, or *forward gain*, of the dipole-reflector combination. It is expressed in decibels, and is typically of the order of 3 to 5 dB.

The power gain of a dipole-reflector combination is much affected by the spacing between the two uprights of the "H". It is maximum with close spacing of about 0·1 wavelength between dipole and reflector, and falls gradually to about 3 dB with quarter-wavelength spacing.



In the *H-TYPE AERIAL* Dipole/Reflector Spacing Determines Forward Gain

It would seem from this that the closer the spacing, the better. Two other factors, however, complicate the problem. If the spacing of the reflector from the dipole is for any reason reduced *below* 0·1 wavelength, power gain suddenly drops very sharply, and there is a sudden large drop in the strength of the signal fed to the receiver. Such a reduction in dipole/reflector spacing could often occur in a roof-mounted aerial, and severe *flutter* in the picture received would result whenever a strong wind blew in gusts. Although power gain is less when dipole/reflector spacing is eased out to between $0{\cdot}15\lambda$ and $0{\cdot}25\lambda$, there is no such sudden drop when the spacing is momentarily altered, and the signal developed at the receiver input is much more stable.

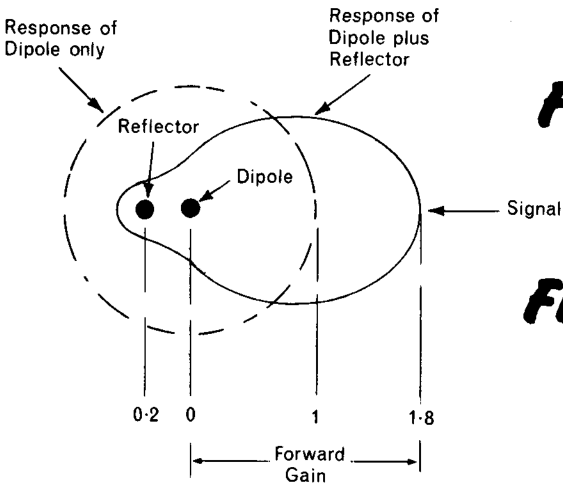
The second objection to over-close spacing of reflector and dipole is that, while the addition of *any* reflector to a dipole reduces the centre impedance of the dipole and so endangers the all-important impedance match with the feeder cable, the closer the spacing, the sharper this reduction in centre Z becomes. At quarter-wave spacing, the reduction is only from 73 to about 60 ohms, which is still tolerable from the matching point of view; but at a tenth-wavelength spacing, impedance at the centre of the dipole can drop to as little as 15 ohms.

Though there are (as you will see in a moment) means of counteracting the effects of a centre Z even as unacceptably low as that, you will gather that the mutual spacing of dipole and reflector is one of the many factors which have to be taken into account when the perpetual compromise involved in achieving a good aerial design is being worked out.

One other technical term is in common use in connection with the simple dipole-reflector combination. The *front-to-back ratio* of the combination provides a measure of the accentuated response of the dipole-plus-reflector in a forward direction (*i.e.*, in a direction pointing towards the signal source), compared with its response in a backward direction. An "H" aerial can often provide a front-to-back ratio of 9 or 10 dB—high enough to be very useful in discriminating against unwanted signals arriving from sources other than the transmitter itself.

VHF Aerials—The Reflector (*continued*)

Be careful not to confuse *forward gain* with *front-to-back ratio*. In the illustration below, the response of a dipole mounted by itself is shown as a dotted circle superimposed on the pear-shaped response of a dipole-reflector combination, drawn in continuous heavy outline. The dipole alone is, as you know, omni-directional, and its value is given (for purposes of the illustration) as unity.



FORWARD GAIN and FRONT-TO-BACK RATIO

The response curve of the dipole-reflector combination is also given for purposes of illustration only. A combination could be designed to give comparative figures of this order of magnitude, but so could lots of others giving different ones.

Say, then, that the response of the combination is 1·8 in a forward direction from the aerial, and 0·2 in a backward direction. The *forward gain* is, of course, only 1·8 : 1, and the addition of the reflector has improved the response of the dipole in that ratio.

The *front-to-back ratio*, on the other hand, is 1·8/0·2, or **9 : 1**; and this ratio expresses the relative efficiency of the combination in a forward direction as compared with its efficiency in a backward direction.

The Shape of VHF Aerials—The Director

It is possible to enhance still further the directive properties of the dipole-reflector combination, and to sharpen still more its frequency response, by adding to it *in front of the dipole with respect to the wanted signal* other lengths of continuous rod known as **directors.**

Directors are similar in appearance to the reflector, and are always fixed in the same plane as the dipole-reflector combination and parallel to it. In length, the first director (*i.e.*, the one immediately in front of the dipole) is normally made about 5% *shorter* than the dipole itself; and each succeeding director is made about 5% shorter than its predecessor nearer the dipole.

The simplest form of dipole-director combination is the **X-aerial** of which you see so many on the roof-tops of Britain today. This type of aerial is described on the next page.

VHF Aerials—The Director *(continued)*

The X-aerial consists of a half-wave dipole plus a director, both bent outwards at an angle of 90° and both rigidly supported at their centre (which is also the approximate centre of gravity of the array) at a common point. To this common junction is fixed the aerial support, down which runs the feeder to the receiver.

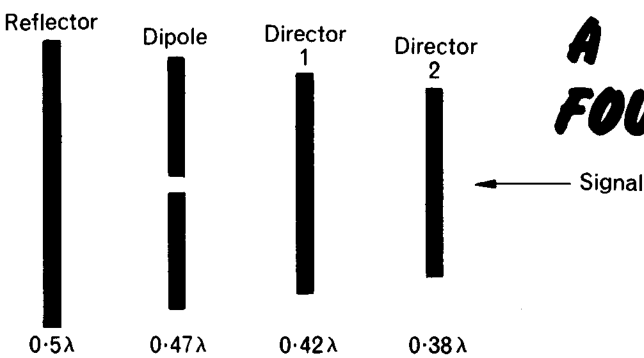
Note that in an X-aerial the dipole is the element *furthest away* from the signal source, whereas in the H-type it is the element nearest to it. In both aerials, dipole size is the same—slightly less than half the wavelength which the aerial is intended to receive.

Pick-up efficiency of the X-aerial is about the same as that of the H-type, but it provides a slightly better front-to-back ratio. It is also somewhat the smaller of the two, because a director is always some 10% shorter than a reflector, and because the bending of the elements makes the array more compact.

The smaller size, superior rigidity and better mechanical balance of the X-aerial make it the easier of the two to erect, and provide a further marginal advantage over the H-type.

Multi-Element Arrays

When an aerial contains a dipole, a reflector and a number of directors, it is known as a *multi-element array.* A theoretical form of such an array, containing four elements only—dipole, reflector and two directors—is illustrated below. (In practice, as you will see on the next page, the dipole in a multi-element array is always of a different shape.)



A FOUR-ELEMENT Array

The addition of director(s) increases both the forward gain and the front-to-back ratio of an H-type aerial by amounts which depend primarily on the number of directors added, and on the degree of spacing between them. In theory, the optimum gain would be achieved by spacing the directors about a tenth of the wavelength apart; but better all-round results are achieved in practice by increasing this spacing to between one seventh and one-eighth of the wavelength (0·14λ to 0·125λ).

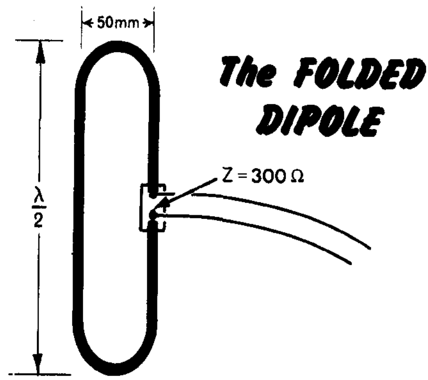
The number of directors used depends on the location of the receiving aerial in relation to the transmitter. In areas where the signal is strong and interference low, no director at all will be needed; and the ordinary H-type or X-type aerial will suffice to pick up even signals in Band 3 with acceptable efficiency. But as distance from the transmitter increases and sources of interference signals multiply, so the number of directors needed grows (especially in Band 3); until in fringe areas double aerial arrays sometimes containing as many as 12 elements may be required.

VHF Aerials—The Folded Dipole

The action of a director array is similar to that of the reflector. Energy from the incoming signal is extracted by the director(s) and re-radiated so that it arrives at the dipole *in phase with* the signal itself.

Unfortunately, however, the addition of directors produces a most undesirable effect on the impedance of the dipole to which they are attached, reducing the centre impedance of the dipole to a level far below an acceptable match with the feeder cable.

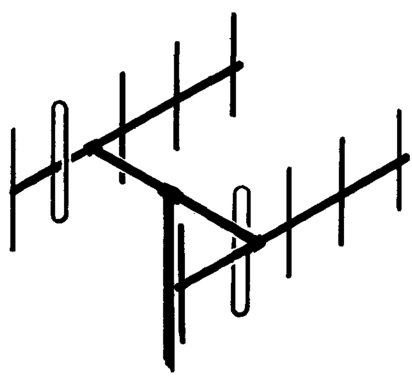
One of the most common ways of overcoming this mismatching (especially in Band 3, where the number of directors needed to pick up an adequate signal is often high) is to fold over the dipole so that it looks like a continuous half-wave element connected in parallel at its ends with an ordinary half-wave dipole, which in turn is cut and tapped to the feeder at its centre point. Another way of looking at the folded dipole is to regard it as a full-wave element folded back on itself with its two sections only some 50 mm (2″) apart, to form as nearly as may be a centre-fed dipole.



The principal advantage of the folded dipole is that the division of the current between its two sections increases the centre impedance of the dipole by a factor of four as compared with the centre Z of an ordinary dipole. With a "natural" centre Z of some 300 ohms, the folded dipole can therefore be reinforced by a reflector and several directors without this impedance being reduced to a level which would present a serious mismatch with the feeder cable.

For this reason, nearly all multi-element arrays require a dipole of the folded type. Its signal-detecting ability is about the same as that of the ordinary dipole, but its frequency response tends to be rather broader.

Multi-element arrays containing folded dipoles are often called **Yagi aerials**, from the name of the man who first introduced them. Band 3 signals in fringe areas often require *multi-element double-Yagi* arrays, such as that illustrated opposite, to pick them up satisfactorily. In such an array, two separate aerials are supported by a common mast, each aerial complete with a reflector, a folded dipole, and 3 or 4 directors. The aerials are mounted one half-wavelength apart, side by side when the polarization of the signal calls for vertical mounting, and one above the other when polarization is horizontal.



It is very important in double Yagi's that the cables connecting each aerial to the common junction should be exactly equal in length. Any significant difference will cause the signals from the two aerials to arrive slightly out of phase with one another, with resulting loss of receiver efficiency. In the worst case, with the signals reaching the junction in full anti-phase with one another, they would entirely cancel out; and no signal at all would get through to the receiver.

VHF Aerials—Polarization

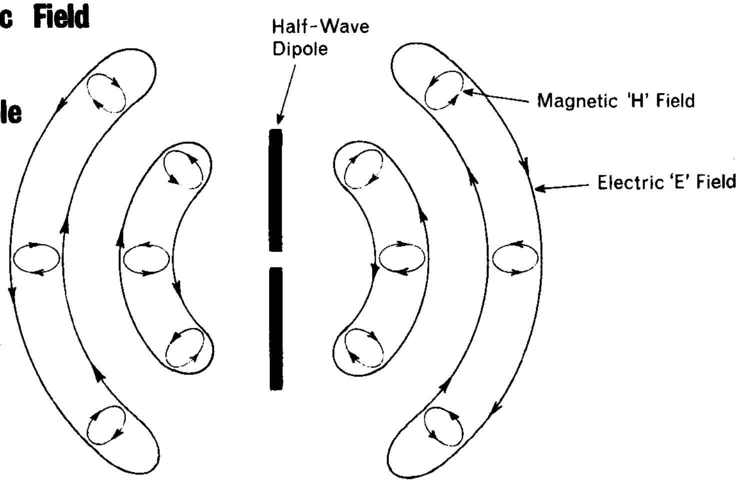
You saw in Part 1 that the sound and vision signals used in TV are always transmitted with a certain *polarization*, and that this polarization depends on the plane in which the electric field of the electromagnetic wave is made to travel outward from the transmitter. It is open to the broadcasting authority to arrange for the polarization of the transmitted wave to be either vertical or horizontal, depending on the technical characteristics of the area to be served.

Rather more than half the TV programmes broadcast in Great Britain in the VHF Bands 1 and 3 are today transmitted with *vertical* polarization; the remainder with horizontal polarization. All UHF transmitters (with the exception of a few "fill-in" stations) are scheduled to radiate waves having *horizontal* polarization.

The efficiency of a receiving aerial of the dipole type is greatly affected by its positioning with regard to the polarization of the signals to which it is required to respond. *Its efficiency will only be maximum if its orientation corresponds to the polarization of the signal to be received.* In other words, an aerial must always be mounted vertically for best reception of a vertically-polarized signal, and horizontally for best reception of a horizontally-polarized signal.

A dipole must also be mounted so that it presents itself *broadside on* to the direction from which the signal is arriving. It thus offers the whole of its length to the *magnetic* field of the oncoming signal, and so allows the maximum number of the lines of force in this field to cut it. (You will recall from *Basic Electricity*, page 1.34, that an electric current is caused to flow in a conductor when a magnetic field is moved across the conductor.)

Electro-Magnetic Field Surrounding a Half-Wave Dipole



VHF Aerials—The Slot Aerial

You should now learn a little about another type of VHF receiving aerial which appears to break the rule about needing to be mounted with a polarization corresponding to that of the signal it is intended to pick up. It is called the *slot aerial.* You will not often see such an aerial mounted on a roof-top; but it has advantages for the "do-it-yourself" enthusiast who wishes to erect a receiving aerial inside a loft, for example, or in the attic of his house.

VHF Aerials—The Slot Aerial (*continued*)

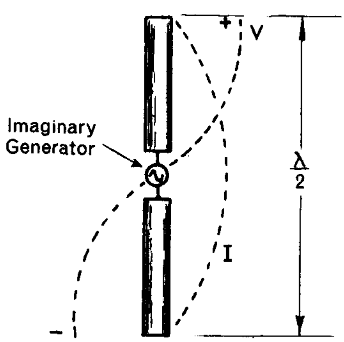
Take a sheet of conducting material and cut out of its centre a rectangular slot running horizontally across the sheet. With the proper electrical connections, this slot can be made to behave as though it were a *vertically-mounted* rod-type dipole, and can be used either for transmitting or for receiving signals having vertical polarization.

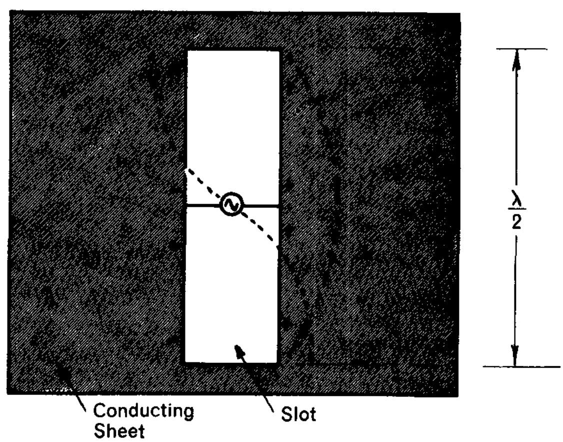
Now turn the sheet through 90° so that the slot lies in the vertical plane, and it will behave as if it were a *horizontally-mounted* dipole. How does this "inverse orientation" property of the slot aerial come about, and can it be put to any use?

You know that when a correctly oriented half-wave dipole is accepting a signal to which it is resonant, a voltage difference is built up between its ends and the current flowing in the dipole is a maximum at its centre. It is as if the dipole were a conductor surrounded by a non-conducting medium, with an imaginary electrical generator connected at its centre.

Now imagine that your sheet of conducting material has had cut out of its centre a slot whose length is equal to that of the dipole (*i.e.*, approximately half the wavelength of the signal which it is intended to receive), and whose width is small in proportion to its length. Imagine also that this slot, too, has an electrical generator connected across it at its centre point.

If the current created by this "generator" is to flow between its two "terminals", the current path must be up one side of the slot, across the top, down the other side, across the bottom and back up the other side to where it started. Since the currents on either side of the slot are flowing in opposite directions, there must be a potential difference between the two sides—which is only what you would have expected, since the terminals of the generator are on opposite sides of the slot and will naturally be of opposite polarity.





The path of least resistance across the slot obviously exists at its two ends, where there is a good conducting connection; and it is at these points that the current reaches a maximum value. Maximum resistance, and therefore minimum current flow, is found across the centre of the slot.

Conversely, the voltage distribution across the slot will be a maximum at the centre, and minimum at the two ends.

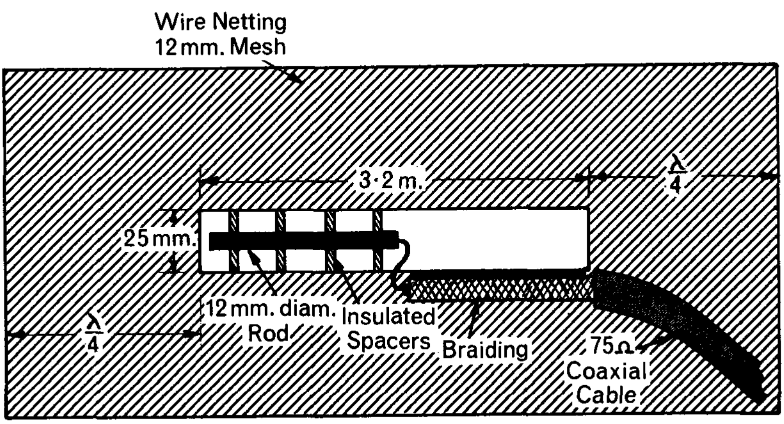
VHF Aerials—The Slot Aerial (*continued*)

It follows from what you read on the last page that the distribution of current and voltage along the half-wave slot cut in the conducting medium is exactly opposite to the distribution of current and voltage along the half-wave dipole situated in the non-conducting medium. So if a slot aerial is to respond with maximum efficiency to a horizontally-polarized wave, it must be mounted *vertically* if the electrical field of the wave is to be able to set up a voltage difference *across* the slot and the magnetic field to create a current *along* the slot. And the reverse applies when a vertically-polarized wave is to be received.

Because the slot aerial has to be aligned parallel with the *magnetic* field of the received wave (whereas a dipole has always to be aligned with the *electric* field), the slot is sometimes referred to as a **magnetic dipole**.

One snag about the slot-type aerial is that the impedance measured at the centre of the slot is about 500 ohms, which obviously creates matching difficulties with the feeder. One of the simplest ways of creating a good match is as follows.

The illustration below shows a slot aerial constructed from ordinary chicken wire, with dimensions suitable for receiving a signal in Channel 1. The *width* of the cut-out slot affects the bandwidth of the aerial in much the same way as does the diameter of a dipole rod. A slot width of 220 to 300 mm (9″ to 12″) is generally suitable for TV reception.



The feeder is connected to the slot by stripping off its outer covering of PVC for a length equal to about half that of the slot, and then soldering the exposed braiding to one side of the slot at short intervals. The centre conductor is then extended and soldered to one end of a stiff rod, slightly shorter in length than half the length of the slot, which is placed inside the slot so that it runs down its centre parallel to its sides. The rod is there fixed firmly in position by means of insulated spacers (typically, thin strips of perspex).

The whole aerial assembly can then be supported from its four corners by strong cords attached to nearby rafters or beams. It should be positioned broadside on to the transmitter for best reception (though a certain amount of offset may sometimes be necessary to reject outside interference or one of the "TV ghosts" which you will learn about later in this Section).

VHF Aerials—The Slot Aerial *(continued)*

In the earlier slot aerials, the conducting "sheet" into which the slot was cut often consisted of ordinary 12 mm (½") wire netting, with a thicker piece of wire joining up the ragged edges of cut wire to form the outline of the slot itself. This was cheap and worked well, but more efficient slots are generally used nowadays.

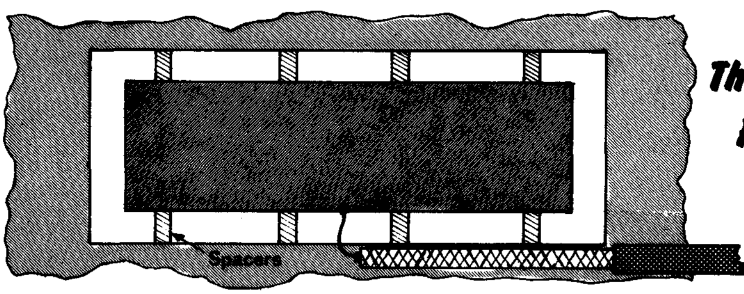
The principal use of the slot-type aerial is indoors, where maintenance is easier and problems of weatherproofing do not arise—generally in a loft or attic in an area of good signal strength. Because it is smaller and needs to be placed horizontally to receive a vertically polarized signal, the slot is much more convenient in such a location than are the big H or X aerials used to receive signals in Band 1.

Moreover, the slot aerial has a better (*i.e.*, more directional) polar diagram than has the half-dipole, and so better selectivity. This selectivity can be further improved by the addition of a reflector element, in just the same way as can the performance of a dipole.

The slot aerial reflector takes one of two forms. It can either be the normal rod-type element positioned the usual distance behind the aerial, or it can be another slot similarly positioned. The main difference between the two types lies in the way they are mounted. The rod-type reflector, being of opposite polarization to the slot, needs to be mounted *vertically* beind a *horizontal* slot; whereas the slot reflectors, having the same polarization as the slot, must be mounted parallel with it.

The dimensions of the slot reflector, and its spacing from the slot itself, are exactly the same as those of the ordinary dipole reflector.

One big disadvantage of the slot reflector is that it *increases* the impedance of the slot, whereas the addition of a reflector to a dipole, as you know, *reduces* its centre impedance. The addition of a reflector to a slot aerial thus increases the difficulties of matching the aerial to the feeder cable running to the receiver. One way of overcoming them is to use an aerial known as the *folded slot.*



The FOLDED SLOT

You know that when an ordinary dipole is folded, its impedance is increased by a factor of four. When a slot aerial is folded, exactly the opposite happens—its centre impedance is *reduced* by a factor of four. This is most convenient, for the 125-ohm impedance of the folded slot is far easier to match to the 75-ohm impedance of the feeder than is the 500-ohm Z of the normal slot. Indeed, the loss of signal will not be more than 1 or 2 dB if a folded slot aerial is connected directly to a 75-ohm feeder.

The folded slot is made by placing a second sheet of conducting material *inside* the original slot itself, holding it in position by means of insulated spacers. The method of connecting a coaxial feeder to a folded slot is similar to that of connecting it to an ordinary slot, but (as you can see in the illustration) a good deal simpler.

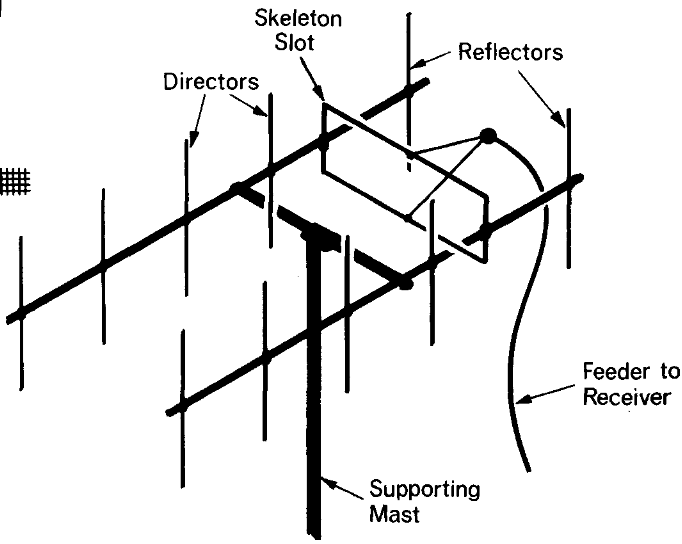
The VHF Aerial—The Skeleton Slot Aerial

Recent experiments on the slot aerial have shown that almost all the conducting material surrounding the slot can be cut away—leaving only the skeleton outline of the slot itself—without affecting the properties of the original aerial. The logical development of this discovery has been the construction of aerials made of ordinary dipole-type half-inch rod having the same dimensions and outline as the original slot.

Such *skeleton slot aerials*, as they are called, are now commercially available for reception in all television Bands. Some are designed with bandwidths wide enough to allow the aerial to operate over a complete Band of frequencies; others to operate over three adjacent channels only. Bandwidth is varied by altering the width of the slot. The naturally high directivity of the slot gives good gain and good rejection of unwanted interference signals.

One British manufacturer has combined the advantages of the Yagi with those of the skeleton slot to produce a composite array having very high gain. An array of this type uses the high impedance of the slot to reinforce the sharply-lowered impedance of the dipole which results when a reflector and a number of directors are added to it.

A Double Yagi AERIAL WITH Skeleton Slot



The illustration pictures an aerial array of this type—one designed to operate over three adjacent channels in Band 3. You will observe that the *horizontal* skeleton slot is teamed up with two *vertical* Yagi's having a total of two directors and eight reflectors between them, to receive a vertically polarized wave. Directivity is very high, the beam width of the polar diagram being only some 60°.

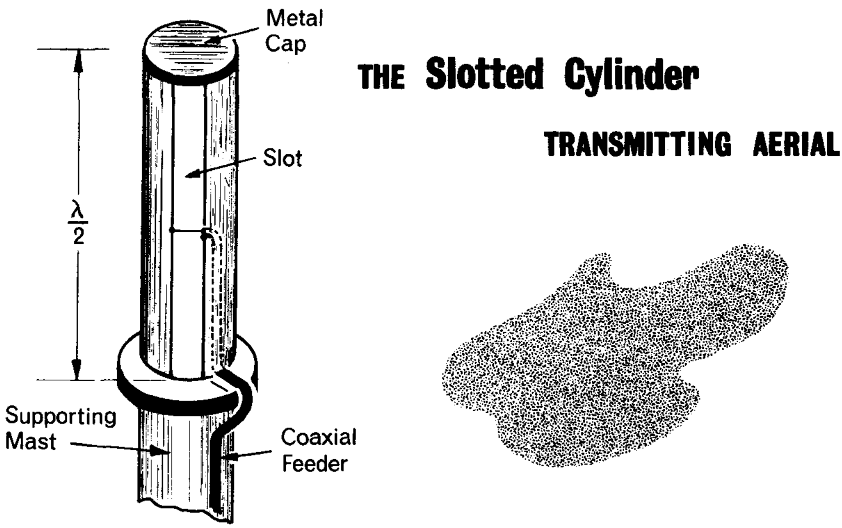
The coaxial feeder is matched to the slot at its centre (through a so-called *delta match* which you will be learning about soon). With the high Z of the slot being reduced by the low Z of the two Yagi's, an excellent match with the 75-ohm Z_0 of the feeder is achieved. It is this good match which gives the array its very high overall gain of some 16 dB.

The Slotted Cylinder Transmitting Aerial

It is perhaps worth while to digress a bit at this point, and to return for a moment to the transmitting aerial.

As you learnt on page 1.129, the principle of the slot is used also in transmitting aerials, one of its most useful applications taking the form of the so-called *slotted cylinder transmitting aerial.* You may remember the description applied to a transmitter of this type when the section of the TV mast housing the slotted cylinder aerials was said to look "rather like a number of the small corner turrets found in mediaeval castles, set one on top of another without their pepperpot roofs".

Here is what the aerial section of such a mast looks like when seen at shorter range.



The slotted cylinder aerial works just like the other slot aerials already described, save that the conducting material surrounding the slot consists of a section of a metal cylinder instead of a flat sheet. It is widely used by the BBC for the transmission of their VHF/fm sound radio programmes in Band 2, the same aerial being used to transmit all three programmes in the Band.

The metal cylinder of a broadcasting aerial of this type forms a natural extension of the supporting mast, and has a large number of slots (typically 32) arranged at 90° intervals round the cylinder in sets of four placed one above the other. This arrangement ensures that transmissions can be beamed with equal efficiency to all points of the compass.

Note that the *vertical* configuration of the slots ensures that the polarization of the radiated signal shall be *horizontal.* The length (or depth, if you prefer it) of all the slots is adjusted to half the wavelength of the mid-band frequency in Band 2.

The comparatively wide-band characteristic of the slot aerial permits the use of a single transmitting aerial to radiate the complete band of frequencies (from 88 to 100 MHz) lying in Band 2. Thus all Band 2 signals can be transmitted from the same point, so that a single receiving aerial can pick them all up. But for this, a viewer would be put to the expense of having to mount several aerials, all pointing in different directions, to pick up all the frequencies radiated in the Band.

The UHF Aerial

Signals in the UHF Bands travel, as you know, on much shorter wavelengths than do signals in the VHF range. They therefore require shorter aerial elements to detect them. In order to produce a signal voltage across its terminals equivalent to that of a VHF aerial immersed in the same field strength, a UHF aerial must therefore be built with a higher power gain to make up for its smaller collection area.

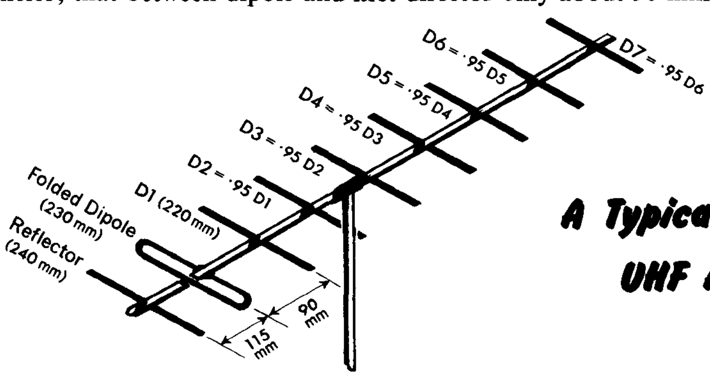
There are at least two other reasons why a UHF aerial system needs to possess a relatively higher power gain than does a VHF aerial. The first is that the signal, though generally no less strong than the VHF signal when it is transmitted, and though it is capable of being transmitted with considerably better directivity, is nevertheless much more easily attenuated by passage through the atmosphere. It therefore weakens with distance from the transmitter more quickly than does a VHF signal of the same original strength.

The second reason why a UHF aerial system needs relatively higher gain is that the aerial needs to deliver to the receiver a signal which is actually *stronger* than the signal which would be acceptable at VHF. All valves, as you know, produce noise when they are used to amplify a signal; and the higher the frequency of the signal to be amplified, the worse this noise tends to become. So with noise at UHF tending to be high, the signal reaching the r.f. amplifier stage in the tuner needs to be about three times as high at UHF as it does at VHF.

With aerial elements which need to be short having to amplify an often weaker signal to a higher power, it is obvious that a UHF aerial array needs to be more elaborate than its VHF counterpart. The principles on which it works, however, are exactly the same; and the extra complexity of structure arises only from the addition of more directors, and from the use of a reflector of different and more efficient design.

By reason of the high frequencies to which it has to resonate, a UHF dipole is only about one-tenth of the length of a dipole tuned to a frequency in Band 1. To take an example about midway through the UHF range, a dipole tuned to a frequency in Channel 39 (614–622 MHz) needs to be about 230 mm (9″) in length, its reflector 240 mm ($9\frac{1}{2}$″), and its first director a little under 220 mm ($8\frac{1}{2}$″). long Subsequent directors still need to diminish in length by about 5% compared with their immediate predecessor nearer the dipole.

Spacing between reflector and dipole needs to be about 115 mm ($4\frac{1}{2}$″) at these frequencies; that between dipole and first director only about 90 mm ($3\frac{1}{2}$″).



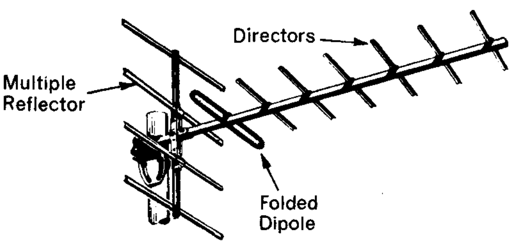
A Typical UHF AERIAL

You will see that, despite their greater complexity, UHF aerials are not physically large; and it is quite easy to design arrays which are neither too heavy nor too cumbersome to be fixed securely on an ordinary roof-top.

The UHF Aerial—The Reflector

Because of the poor signal-collection efficiency of the short individual elements in a UHF aerial array, and because a relatively stronger signal is nevertheless needed by the UHF receiver, the problem of *gain* is of first importance in UHF aerials. Anything which will give more gain is generally worth adding to the array, even if it brings difficulties with it. (These difficulties, of course, mainly affect the correct matching of the aerial itself to the feeder cable running to the receiver.)

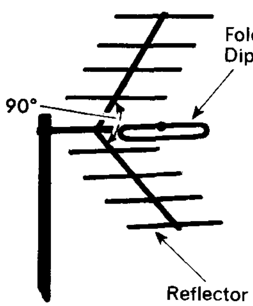
The *reflector* is the element on which chief reliance is placed to achieve more gain in a UHF aerial. You will note that in the illustration below the reflector has become a four-element affair erected with the same polarisation (horizontal) as a six-element director array. This four-element reflector is placed a carefully calculated distance behind the aerial, the object being (as with all reflectors) to ensure that the re-radiated signal from the reflector should reach the aerial *in phase with* the signal itself.



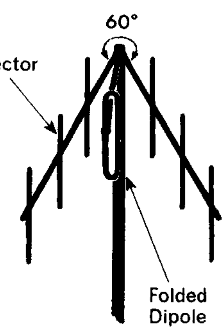
UHF Aerial WITH REFLECTOR

Note that the dipole used is of the folded type. An aerial having a high "natural" centre Z of its own is always required in a UHF array to offset the impedance-lowering properties of the multiple reflector-and-director arrays which are needed to give the aerial adequate gain.

Another type of reflector which is sometimes used to give added gain to a UHF aerial is the *corner reflector*. Two types are shown below—the horizontally and the vertically polarised, with differing angles of inclination.



UHF Aerials with CORNER REFLECTORS



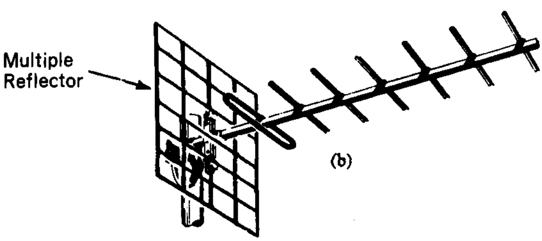
Note that the two halves of the multiple reflector are bent inwards towards the folded dipole aerial, which has *no directors*. The angle of inclination between the two halves of the reflector can vary between 60° and 90°.

The advantage of the corner reflector is that it gives high forward gain—typically between 9 and 11 dB.

The UHF Aerial—The Wire Mesh Reflector

A more common type of reflector used with the UHF aerial is the *wire mesh* type. Theoretically, the ideal reflector would consist of a flat sheet of metal, of infinite dimensions; for re-radiation of the transmitted electromagnetic waves would, from such a surface correctly positioned behind the aerial, be maximum. But the cost of such a sheet, and the practical difficulties of mounting it securely on an ordinary roof-top, would be great; and it has been found that results almost 90% as good can be obtained from a quite small rectangular grid consisting of closely-spaced wire rods, or of heavy wire mesh, erected at the correct spacing behind the folded dipole.

The important point is that the spacing between the rods (or between the vertical/horizontal wires in the mesh, depending on its polarisation) shall not exceed one-tenth of the wavelength ($0{\cdot}1\lambda$) of the signal.



The WIRE MESH Reflector

The UHF Aerial—Acceptance Bandwidth

All Britain's TV Broadcasting at UHF has been planned in advance to allow an eventual choice of four programmes in every viewing area. At present, only three of these programmes are being broadcast; but the eventual pattern will be two BBC and two ITA programmes available in most parts of the country.

In order to save money, it is planned to radiate all four of these programmes from a single transmitting station in each viewing area (the technique is called *co-siting*). Frequencies must obviously be chosen for these programmes which will not interfere with one another. Channels in each area have therefore been allotted on a wide separation basis. In the London area, for instance, the channels allotted are 23, 26, 30 and 33; and this formula—n, $n+3$, $n+7$, $n+10$, where n is the channel number of the lowest frequency to be broadcast—will hold good, with small variations, over the rest of the country.

London's four channels thus cover a frequency range of 486 MHz to 574 MHz; and this *total frequency range of 88 MHz* will also be approximately the rule elsewhere in Britain.

It is obviously desirable that a single receiving aerial shall be capable of receiving efficiently over all this frequency range. The alternative would be four UHF aerials on every roof, and a complicated and "lossy" sharing network to couple all four of them into the single input terminal of the receiver. All British UHF aerials are therefore designed to have a more or less even frequency response over the wide bandwidth of 88 MHz. Their *acceptance bandwidth* is therefore broad.

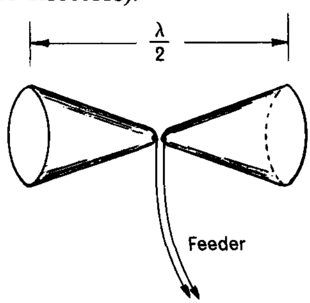
The UHF Aerial—Acceptance Bandwidth (*continued*)

This broadening of the acceptance bandwidth is generally achieved by *increasing the ratio of element diameter to element length.* Since UHF aerial dipoles are not very long anyway (less than 300 mm, or 12″, in all cases), this extra thickening results in their acquiring a generally "tubbier" appearance than that of their VHF counterparts.

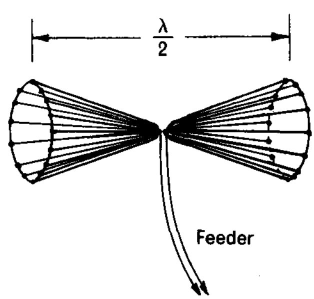
Two consequences of thickening a dipole should be noted. The first, as you already know, is to lower the centre impedance. When the diameter of a 12 mm (½″) dipole is increased to 60 mm (2½″), to give a typical example, centre Z is reduced from the neighbourhood of 73 ohms to about 40 ohms.

The second consequence of a thicker dipole is that the velocity of the electromagnetic wave travelling through it is still further reduced in comparison with the velocity of the same wave when travelling in space. You already know that this loss of velocity needs to be compensated by reducing the length of the "half-wave" VHF aerial of 12 mm diameter by about 5%. At UHF the corresponding reduction needs to be 10%. The "half-wave" UHF dipole of 60 mm diameter thus needs to be cut to a length of about 0·45λ.

Some UHF aerials, particularly in the United States, achieve the required broadened bandwidth by changing their shape. Typical of these is the so-called *conical dipole* (it should strictly be called the "bi-conical dipole", as you will see from the illustration below; but it seldom is). The two cones have a comparatively large diameter at their ends (which gives them the broadened bandwidth), but taper to a very small diameter at their inner ends (which helps to keep their centre Z high enough to offset the diluting effect of directors).



The Conical Dipole

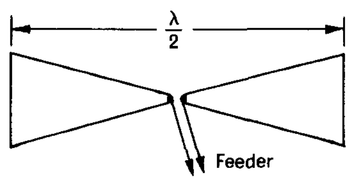


The Simulated Conical Dipole

The conical dipole may either be constructed of hollow cones of sheet metal, or the cones may be *simulated* by a suitable arrangement of thin metal rods so as to offer less resistance to wind.

Another similar shape of dipole, also to be seen in Britain, is the so-called *bat-wing aerial.* With its wings made of flat sheet metal or wire mesh shaped into two elongated triangles, it has the same properties of wide acceptance bandwidth and adequately high impedance at the point where it is tapped by the feeder.

The Bat-Wing Dipole



The UHF Aerial—Positioning and Alignment

UHF aerials are, as you have seen, highly directional. Their accurate positioning and alignment are therefore of great importance.

In general, the best position for the UHF aerial is as high above ground as you can get it. It should also be positioned well away from all other aerials, for their proximity can alter the centre impedance of the UHF dipole, resulting in what looks like a reduction of the bandwidth over which the dipole will accept signals.

Yet here, as always with aerial design and mounting, there is need for compromise. For if you fix your UHF aerial as far away from other aerials as you possibly can—say, to a second chimney—a greater length of feeder cable will be needed to connect the aerial to the receiver. As you will see shortly, all feeder cables tend to attenuate signals passing along them; and the longer the feeder, the worse the attenuation. You know how important aerial gain is at UHF; so it is important not to impair it by putting into the aerial circuit more feeder than is absolutely necessary.

Exact orientation of the UHF aerial is best done by a professional rigger armed with a piece of equipment called a *UHF signal strength meter*. This is connected to the feeder, and the aerial is then slowly rotated until a maximum reading on the meter is achieved.

The service area of a UHF transmitter tends to be more sharply defined at the edges than is that of a VHF station; yet conditions for reception at points *within* the service area are far less predictable.

The very high frequency of the electromagnetic waves carrying the UHF signal cause them to move in a more or less straight line, almost as if they were waves of light. These direct waves travel in a straight line to the edges of the service area, and then continue on into space. Very little of them is diffracted over the edge of the line-of-sight horizon to receiving aerials situated below it.

Within the service area, different factors come into play. The UHF signal, with its much higher frequency, is far more easily blocked by large objects—hills, gas-holders, large buildings and even the foliage of trees—than is the VHF signal. Aerials situated directly behind such objects with respect to the transmitter tend to be *shielded* from the signal by them, and to receive the signal either much attenuated or not at all.

For the same reason, the walls of a house, and its roof, often prevent the use of an indoor aerial for UHF reception, even when the transmitter mast is close enough to be seen through the kitchen window.

Irregular ground within the service area, moreover, often gives rise to standing wave patterns (alternate regions of high and low signal strengths), and the vertical or horizontal adjustment of a UHF aerial by a few decimetres or a few degrees can sometimes make all the difference between a good picture and a poor one.

The reason why a high-frequency wave suffers greater attenuation when passing through a physical obstruction than does a lower-frequency wave passing through the same obstruction is that the wavelength of the shorter wave approaches more closely to the electrical length of the molecules constituting the obstructing material. You know that when the electrical length of a conductor approaches one-half of the wavelength of a signal applied to it, the conductor starts behaving as a series-tuned resonant circuit and absorbs energy from the signal. Even the shortest UHF wave is, of course, much longer than the molecular length of the obstructing material; but it is a great deal closer to that critical dimension than is any VHF wave, and so loses more of its energy.

Television Ghosts

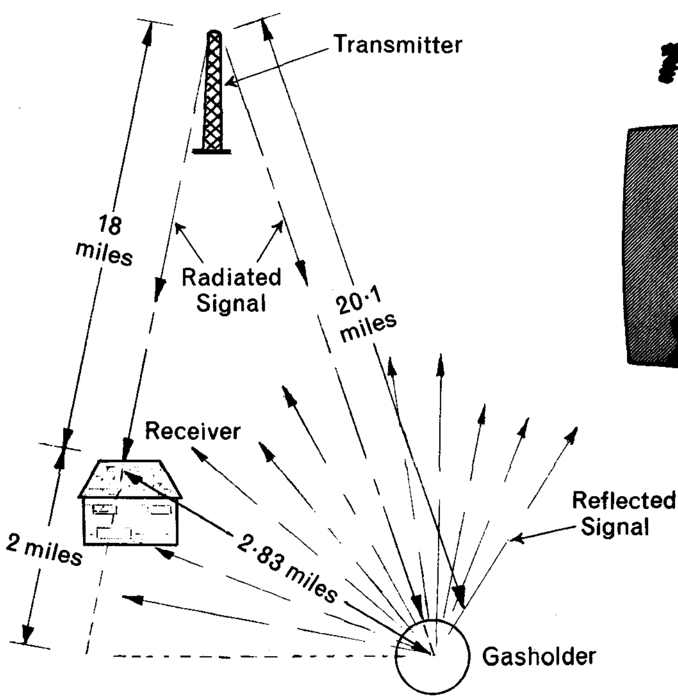
In addition to undergoing greater attenuation than the VHF wave, the UHF signal is also more liable to be reflected off objects (particularly metal ones) in the service area, in such a way that the reflected wave interferes with proper reception by an aerial to which the signal is also travelling direct. Such reflection is always more pronounced from objects whose length is equal to, or greater than, $\lambda/2$ of the signal, so that there are many more potential reflectors of the shorter UHF signal than there are of the longer VHF one.

In theory, therefore, the problem of interference from what are known as **TV ghosts** should be much worse at UHF than it is at VHF; and it is worth a brief discussion of the ghost phenomenon before you see why in practice this is not true.

A television ghost is the name given to a second, sometimes watery-looking, duplicate of the wanted picture which appears on the screen some little way to the right of the picture itself. It is produced when the wanted signal reaches the receiving aerial twice—that is to say, by two routes, one longer than the other.

When the difference in length between the two routes is large, the ghost picture appears completely separated from the main picture, and it is possible to see two entirely separate pictures of the scene side by side. When the difference between the routes is small, the ghost picture occurs only slightly to the right of the main picture and gives it a fuzzy, un-focused outline.

In the illustration below, the receiving aerial is situated 18 miles (29 km) from the transmitter, and the large metal gas-holder rather further away from it at 20·1 miles (32 km). Distance from receiving aerial to gas-holder is 2·83 miles (4·5 km); and both have an uninterrupted view of the transmitting mast and of each other.



Television Ghosts (*continued*)

The signal radiated from the transmitting mast travels outwards as a broad beam, reaching the receiving aerial first and appearing on the picture screen in the normal way. A little later, the signal also reaches the gas-holder. Being large and made of metal, this reflects the signal—some of it in the direction of the aerial. The aerial, having been tuned to accept a signal of this wavelength, obediently picks it up; and in due course the reflected signal also is displayed on the screen.

Since the two signals were received at different moments of time, they will be displayed at different points on the screen. You know that the raster on the picture tube is traced out by the scanning beam moving from left to right of the screen, and that the received signal is used to modulate this beam. So if two identical signals are applied to the picture tube, one rather later than the other, the later picture will be displayed on the screen by the side of the first one, but to its *right* as you look at it from your armchair.

Now for some simple sums, all done in Imperial rather than metric measures because that is how they were originally worked out and the principle is the same whichever system is used. The signal received direct from the transmitter had to travel 18 miles. The signal reflected from the gas-holder had to travel $20{\cdot}1 + 2{\cdot}83 = 22{\cdot}93$ miles—a difference of 4·93 miles. Since radio waves travel at 186,000 miles per second, the time taken for the signal to travel this extra 4·93 miles must be:

$$\frac{4{\cdot}93}{186{,}000}\text{ seconds} = \frac{4{\cdot}93 \times 10^6}{186{,}000}\ \mu\text{s} = \mathbf{26{\cdot}5\ microseconds}$$

Now consider the picture tube. The scanning spot traces out one line of the raster in a period equal to about 57 microseconds in the British 625-line system, this being the effective time-duration of the line after allowance has been made for the blanking period. On a 19-inch picture tube, the actual width of the screen is about 16 inches. The distance travelled by the scanning beam in a period of 57 microseconds is thus 16 inches, and the *speed* of the scanning beam is 16 inches divided by 57 microseconds, or **0·281 microseconds per inch.**

With the reflected signal being received 26·5 microseconds after the real signal, the scanning beam will travel $26{\cdot}5 \times 0{\cdot}281 =$ **7·5 inches** during this delay period. This means that the ghost will appear 7·5 inches along the scanning line *after* (and so *to the right of*) the point at which the main signal is displayed.

Working the same calculations backwards, you can establish that a 16-inch-wide picture tube represents a distance of $(186{,}000 \times 57 \times 10^{-6} =)$ 10·6 miles. With this knowledge it is possible to estimate fairly closely the distance from the receiving aerial of an object causing a ghost picture. Identification of the object is thus made much easier.

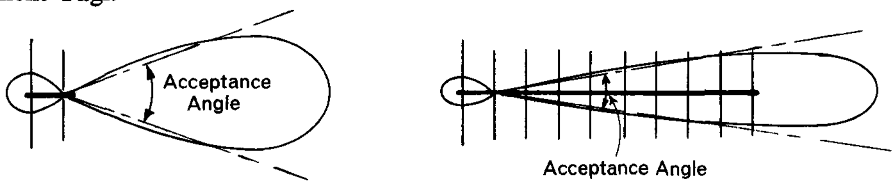
Ghost signals are of two main kinds, positive and negative. When the signal reflected from an object appears at the receiving aerial in phase with the main signal, it will add to the main signal carrier and will produce a *positive ghost*. This means that the tonal content of the ghost picture will be more pronounced than that of the main picture itself (we are still talking of the British 625-line system, which uses negative modulation on the vision carrier).

If, on the other hand, the ghost reflection arrives at the aerial *in anti-phase* with the main signal, a *negative ghost* picture will be produced whose tonal content will be less pronounced than that of the main picture.

The TV Aerial—Acceptance Angle

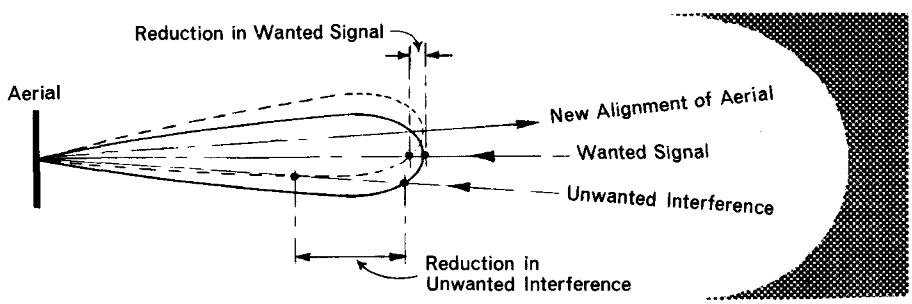
You will see that the liability of an aerial to pick up reflected signals is proportional to the degree to which it is prone to pick up signals reaching it from the side (from the side, that is to say, by reference to the direction of the transmitting aerial). The more highly directional the aerial, the less its liability to pick up ghosts.

You know that a multi-element array has good directional properties. As more elements are added to the bare dipole, so the polar diagram of the aerial becomes narrower and narrower, and its liability to pick up signals from an unwanted direction becomes less and less. The **acceptance angle** of an array is the angle between the two points on the polar diagram (one on either side of the axis) at which signal strength has dropped by 50%. The illustration below shows this angle superimposed on the polar diagrams of (on the left) a dipole-and-reflector-only array and (on the right) of a 10-element Yagi.



The narrower beam of the 10-element Yagi is typically some 35°. Aerials used in radar and in radio astronomy have beamwidths of a few degrees only.

A way in which the narrow acceptance angle of a multi-element array can be utilized in the rejection of unwanted signals is shown in the diagram below. The solid-outline polar diagram (or *lobe*) is that of the array when the aerial is pointing straight at the transmitter and so is receiving maximum signal. Unfortunately, when it does so it also picks up strong interference from another source nearly in line with the transmitter, and the picture on the screen is impaired.



If the array be now made to point *a little away* from the direction of the transmitter, its polar diagram will be that shown in dotted outline above. There will be, as you can see, some reduction in the strength of the wanted signal picked up, but a much larger reduction in the strength of the unwanted signal. The resulting improvement in the *signal-to-noise ratio* of the picture displayed will more than compensate for the small loss of signal strength picked up.

The "exorcism" of a TV ghost can often be achieved in this way—by turning the aerial slightly away from the transmitter but in a direction unfavourable to the ghost signal. This technique of adjusting aerial orientation can often be usefully employed in the vertical plane, as well as in the horizontal.

Stacked Aerial Arrays

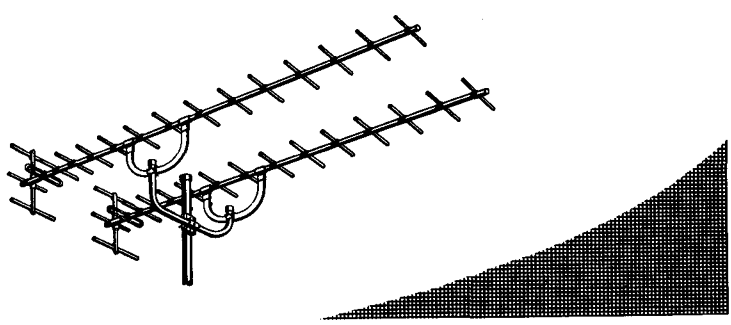
You have just seen that the directivity of an aerial is increased by the addition of more director elements, and that this improvement in directivity carries important advantages. Yet you also know that, beyond a certain point, the addition of more directors to an array defeats the primary object of the addition—which is to increase aerial gain. This happens because the resonant impedance of the dipole is reduced more and more as each extra director is added, until it becomes so low that the additional gain given by one more director is cancelled out by a greater *loss* of gain caused by increased aerial-to-feeder mismatch.

There are several techniques used to compensate for this reduction in resonant impedance (the use of the high-Z folded dipole is, as you have seen, one of them). A rather costly but very efficient one, which has the added advantage of giving excellent directivity, is to mount two similar but quite separate aerials side-by-side (or one above the other if the polarization of the wanted signal is horizontal) on the same mast.

Such an assembly is known as a *stacked aerial array*. A typical UHF variety, such as will often be found in fringe reception areas, is illustrated below.

A UHF STACKED AERIAL ARRAY

(SIDE-BY-SIDE STACKING)



The two halves of a stacked aerial array are normally mounted one half-wavelength apart. Great care must be taken to see that the length of feeder cable running from each aerial to the common junction point is exactly equal, so that the signals picked up by the aerials shall arrive at the junction correctly in phase with one another.

If this is done, and if correct matching between the aerials and their respective lengths of feeder is achieved, two identical aerials stacked in this way will yield twice the gain of either aerial singly, and will also usefully concentrate the acceptance angle of the array in the desired plane.

An aerial array can be stacked with its two halves either one above the other, or side by side. The side-by-side arrangement shown in the illustration is much the more common of the two because it almost eliminates interference signals coming from either side—directions from which most interference signals must obviously originate.

Aerial Feeder Cables

The signals collected by the aerial are, as you know, transferred to the receiver by means of a length of special cable called a transmission line, or *feeder*. Many types of feeder cable are made, but in Britain only the **coaxial** type is used for television.

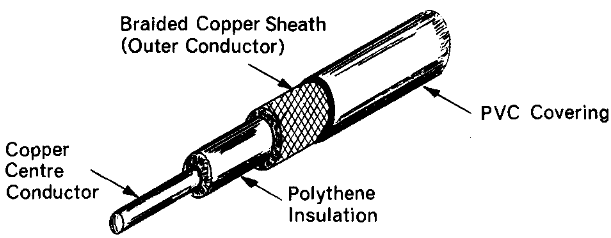
A coaxial feeder consists of a copper conductor of small diameter running through the centre of, but insulated from, a braided copper *sheath*. It is the coaxial arrangement of these two conducting elements which gives the cable its name. The sheath has a protective covering, usually of PVC, to make the cable waterproof and to protect it from abrasion.

The insulating material used between the two conductors (the core and the braided copper sheath) varies. The reason is that no feeder can pass a signal without attenuating it to some extent, but that some types of insulation cause less attenuation than others. These latter types tend, however, to be more expensive, and are therefore only used when signal attenuation needs to be kept to a minimum.

Signal losses increase, of course, the further they have to travel through a feeder; so it is customary to measure the loss in *decibels per 100 foot of cable run*, and to grade different makes of cable accordingly.

Cable losses also increase with the frequency of the signal being passed, at a rate approximately equal to the square root of the frequency. They are therefore more serious at UHF than at VHF—yet it is at UHF, you will recall, that loss of signal can least be afforded. Cable insulation at UHF needs therefore to be better than it does at VHF.

In Band 1, it is possible to use as insulating material a quarter-inch-thick solid insulating sheath of polythene. This is cheap, but the polythene absorbs part of the signal.



In cables used at higher frequencies, it is usual to keep the two conductors insulated from one another by means of a thin strip of polythene wound spirally round the centre conductor. Such a cable is more expensive to manufacture, but it contains less polythene so that less of the signal is absorbed. A spongy type of synthetic material, of cellular construction, is sometimes used as an insulator in UHF feeder cables.

Cable losses tend to decrease when the thickness of the conductors used is increased. In areas of poor signal strength it is therefore often useful (though always more expensive) to use cables of considerably larger diameter.

The fact that cable losses increase with the frequency of the signal means that a feeder good enough to pass VHF signals is seldom good enough to pass UHF without unacceptable attenuation. A joint VHF-UHF downlead, provided the cable is of good quality, is sometimes enough in areas where the UHF signal is very strong; but it is usual for British Dual-Standard receivers to have two input sockets, with separate feeder cables (the UHF one of superior quality) running down into them from the respective aerials.

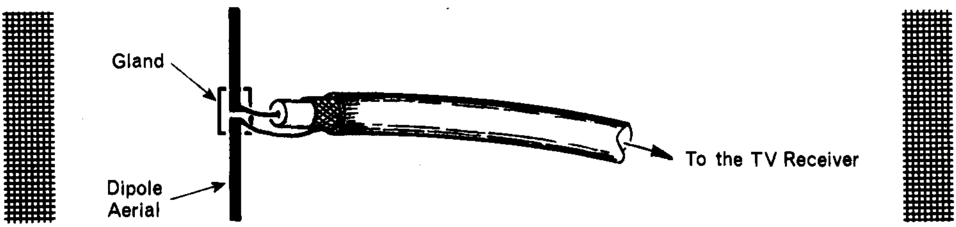
Aerial Feeder Cables (*continued*)

UHF signal strength can be increased in areas of poor reception by connecting into the aerial circuit special transistorised *UHF amplifiers*. These are capable of stepping up a weak signal, and so improving the signal-to-noise ratio in the first stage of the receiver. They are usually fitted near the receiver end of the feeder, where they can be conveniently powered either from the mains or by a small battery of their own.

You already know how important the *characteristic impedance* (Z_0) of the feeder cable is in aerial construction. In a coaxial cable, the Z_0 is determined by the ratio of the inside diameter of the copper braiding to the diameter of the centre conductor. It is, as you have seen, standard practice for these conductors to be so made that the Z_0 of all feeders approximates to 75 ohms. The impedance of the aerial itself is then, by one means or another, made to conform to this standard impedance.

At the receiver end, the 75-ohm impedance of the feeder is matched to the relatively high input impedance of the r.f. amplifier valve in the tuner, usually by means of a small coupling transformer.

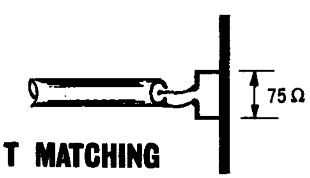
The feeder is normally connected to the centre-fed aerial dipole in the manner shown in the illustration below, one quarter-wave section of the dipole being fed to the centre core, the other to the copper braiding forming the outer conductor. The joint is made rigid and weatherproof by being enclosed in a container sometimes called a *gland*. This is a small junction box whose lid is fitted with a rubber gasket.

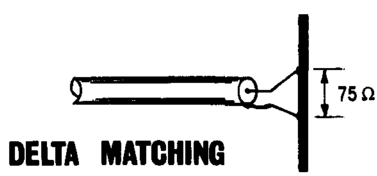


Two other methods of connecting the feeder to the dipole are sometimes used. They are closely similar, and are called respectively *T-matching* and *delta-matching*. The object of both techniques is to overcome the mismatch which occurs between the centre Z of the dipole in a multi-element array and the standard impedance of the cable.

You know that the impedance distribution along a dipole rises progressively from a low figure at the centre (it can be as low as 15 ohms in a multi-element array) to a figure of several thousand ohms at its ends. Somewhere along each arm of the dipole there will be a point at which the impedance is exactly equal to the Z_0 of the feeder. If the two wires leading to the conducting elements of the cable are connected to these points, a perfect match will result.

The connection is usually made through a pair of rods fixed to the dipole at the correct matching points. The shape of the resulting connection resembles either the letter T (see left-hand sketch below) or the Greek letter *delta*.

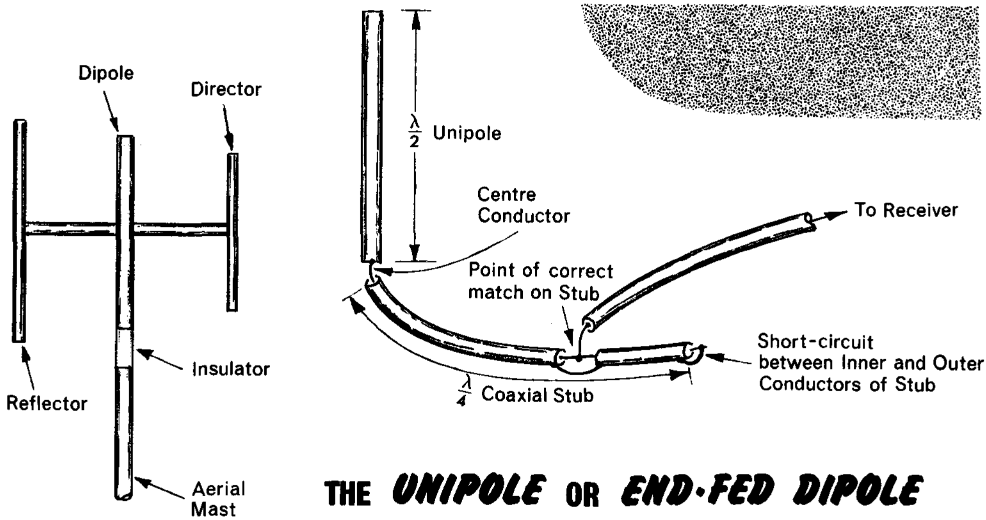




The Unipole, or End-Fed Dipole

Another method of overcoming the problem of securing a good match between dipole and feeder has been successfully tried by at least one British manufacturer.

In this method, the dipole no longer consists of two quarter-wavelengths of rod tapped to the feeder at their centre point, but of a single length of rod, half a wavelength long, tapped to the feeder at one of its ends. The method of operation of such an *end-fed dipole*, or *unipole*, can be followed in the diagram below.



THE *UNIPOLE* OR *END-FED DIPOLE*

The end of the dipole (where the impedance, you will recall, is several thousand ohms) is connected to the centre conductor of a special piece of coaxial cable whose length is exactly equal to one quarter-wavelength of the desired signal, and whose inner and outer conductors are connected (and therefore short-circuited) at the end furthest from the dipole.

A $\lambda/4$ feeder so connected behaves like a $\lambda/4$ stub; and (as you learnt on page 4.55 of *Basic Electronics* and in the first Part of this present Series) it is a characteristic of such a stub that it has a very high value of impedance at the open-circuited end. This end of the stub therefore presents a good match to the high impedance at the end of the dipole.

At the other (short-circuited) end of the stub, impedance is of course zero; so you have a situation in which Z rises along the length of the stub from zero to a high value. If, therefore, the feeder cable is tapped into the stub at the exact point along its length at which a perfect impedance match is available, maximum transfer of signal will be achieved.

Tapping is done by removing the PVC covering, the outer conductor and the polythene insulation from the stub at the desired point, and connecting the centre conductor of the feeder to the exposed centre conductor of the stub. The severed ends of the outer conductor of the stub are re-connected across the gap; and the outer conductor of the feeder is connected to the centre conductor of the stub at its short-circuited end.

The points at which the stub is connected to the end of the dipole, and the feeder to the desired point along the stub, are usually encased in insulated weatherproof glands to give protection and to ensure maintenance of electrical connection.

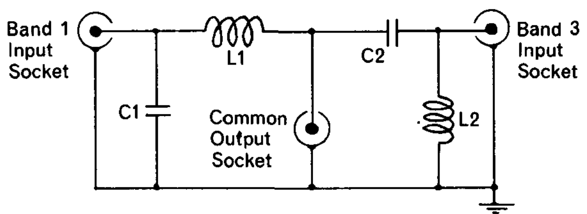
The Diplexer

The British Dual-Standard TV receiver has two input sockets only. One of them is reserved for the feeder coming from the UHF aerial. The other has to accept all VHF signals, in Band 3 as well as in Band 1. Since separate aerials are used to detect the VHF signals arriving in these two Bands, some arrangement is needed for combining the two signals into a common feeder leading into the receiver.

Combination can be effected either at the aerial end of a common downlead from both aerials, or at the receiver ends of two separate downleads. In practice, it is generally less expensive to combine the signals near the aerials.

You might think that the leads from two separate aerials could be combined anywhere, and without difficulty, simply by connecting the leads in parallel to the receiver. The trouble about this solution is that the signals from one aerial would always be getting into the aerial circuit of the other, upsetting the characteristic impedances of both circuits and impairing reception in both Bands. Combining must be done in such a way that each aerial circuit presents a very high impedance to signals from the other.

This is the job of the **diplexer**—a device which is also sometimes known as a *cross-over network* or (for obvious reasons) as a *combining unit.*



THE DIPLEXER

CIRCUIT DIAGRAM

Diplexer units commonly take the form of fully shielded metal boxes slightly larger than a match-box. Each has three connecting points for coaxial feeder cables. These points may be used (as you will see in a moment) either as two inputs and an output, or as one input and two outputs.

Diplexers each contain essentially two inductors and two capacitors connected in two *LC* pairs in such a way as to form two frequency-selective filters, one low-pass to let the lower-frequency Band 1 signal through to the output socket, the other high-pass to let the Band 3 signal through. The best way of understanding how the filters work is to read what follows in conjunction with the double illustration on the next page. This shows, at the top, the *effective circuit* of the diplexer when a Band 1 signal arrives; and, below, the *effective circuit* when a Band 3 signal arrives.

Take the Band 1 signal first. As it leaves its input, it "looks into" two possible paths. One is through C_1, connected in parallel; the other is through L_1, connected in series. The values of these components are so chosen that L_1 offers a low reactance to the Band 1 signal and C_1 a high reactance. The signal, as always, takes the path of least resistance, and passes through L_1.

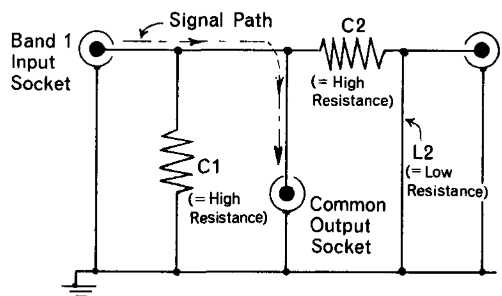
On emerging, it again "looks into" two possible paths—C_2 and the common output socket. The value of C_2 is chosen to give it a high reactance to a signal of Band 1 frequency, so the signal tends to choose the easier path to the output socket. Any part of it which does manage to struggle through C_2 is kept out of the Band 3 input by giving L_2 such a value as to offer very low reactance to a Band 1 signal. The remainder signal thus chooses this path, and is "shorted" to earth.

The Diplexer (*continued*)

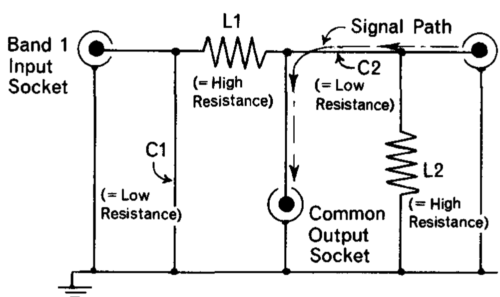
Now consider the Band 3 signal. On leaving its input socket, it confronts two components, C_2 in series and L_2 in parallel. But the value of C_2, which offered high reactance to the Band 1 signal, now (by careful selection of its value of capacitance) offers low reactance to a signal of Band 3 frequency; and L_2, previously so ready to pass the remnant of the low-frequency Band 1 signal, now (by equally careful selection) strongly opposes the passage of a Band 3 signal.

The signal therefore takes the easy route through C_2, and is again confronted with two possible paths—an easy one to the common output socket, and a much harder one through a now-high-reactance L_1 backed up by a now-low-reactance C_1 waiting to pass any surviving signal to earth.

In short, C_1 and L_1 function as a low-pass filter, and C_2–L_2 as a high-pass filter, to all signals of Band 1 frequency; while for signals in Band 3 the roles of the two *LC* pairs are reversed.



EFFECTIVE DIPLEXER CIRCUIT when a Band 1 signal arrives



EFFECTIVE DIPLEXER CIRCUIT when a Band 3 signal arrives

Go back now to that bit on the last page in which you read that a diplexer could also be used as a single input feeding a signal of two different frequencies to two appropriate outputs. How could the diplexer be used in this role?

In the older types of receiver designed for VHF only, two input sockets were sometimes provided—one for Band 1 signals, the other for Band 3. Owners had a choice of leading two separate downleads from the appropriate aerial into the appropriate socket; or they could combine the signals near the aerials, pass them through a single downlead, and then split them again near (or inside) the receiver itself.

The Diplexer (*continued*)

The splitting of the signals mentioned at the foot of the last page was achieved by means of another diplexer, having the role of one input and two outputs. This diplexer was mounted either *outside* the receiver with the signals being fed after splitting to two separate sockets in the receiver, or *inside* the receiver itself with the still-combined signals arriving through a single socket.

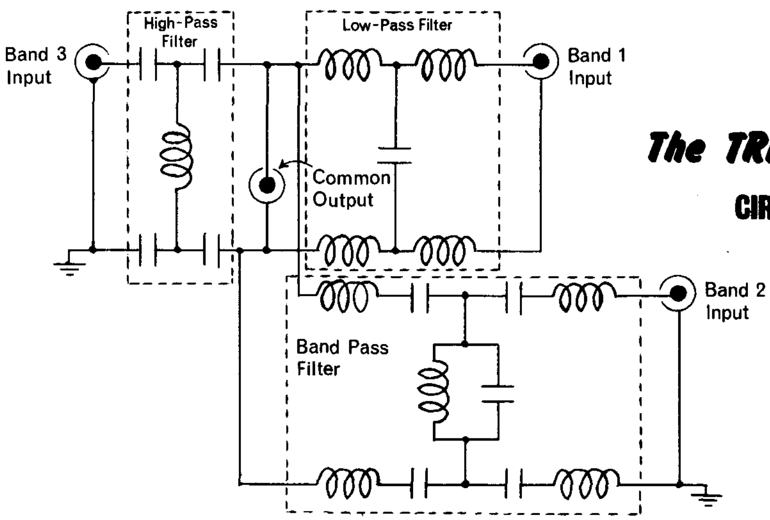
Work out for yourself the path of a Band 1 or Band 3 signal arriving at the *Common Output Point* in the illustration on page 2.49, and making its way through the appropriate low-pass or high-pass filter to its exit at one of the *Input Sockets*. You will see that it is again a question of choosing values of L and C which will offer the correct amounts of reactance or impedance to the signals of different frequency.

Note, by the way, that though a single downlead has obvious economic and aesthetic advantages over a double downlead, and is easier to maintain, it will lead to some attenuation of the signal by reason of the small losses which are inevitable in the combining and re-separating processes.

The Triplexer

This is a rather more complicated form of diplexer used for passing the signals derived from *three* aerials into a single feeder, or *vice versa*. It is used in TV receivers which have separate input sockets for Band 1 and Band 3 signals, and which can also receive the BBC's sound radio transmissions at VHF in Band 2.

The circuit diagram of a typical triplexer is shown below. The essential addition, you will see, is a *band-pass filter*. A filter of this type offers minimum opposition to frequencies lying within a certain band of frequencies only. To all other frequencies, whether higher or lower than this favoured band, the opposition it offers is very high.



The TRIPLEXER

CIRCUIT DIAGRAM

The band-pass filter components in the triplexer will be given values such that the filter will offer minimum impedance to all frequencies in Band 2 (87·5 MHz to 100 MHz), and maximum impedance to all frequencies outside this range. The high-pass filter and the low-pass filter behave just as they do in the diplexer; and it is not difficult to see how the three filter circuits can be used to isolate the three aerial circuits from one another and yet allow their individual signals to pass to a common output.

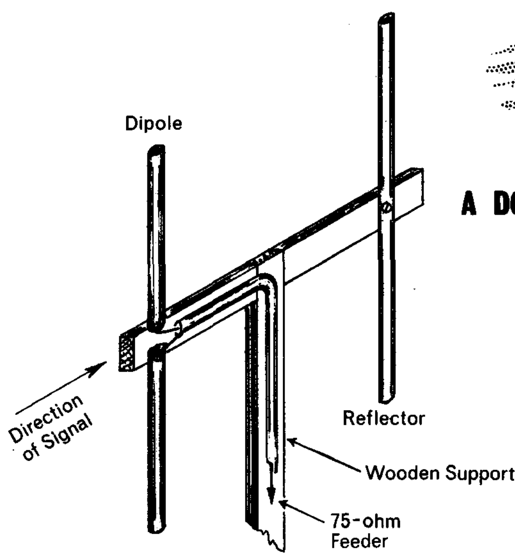
Home-Made Aerials

Home-made aerials are best erected indoors, in a loft or attic, where maintenance is easy and problems of weatherproofing do not arise, and where there is no need for extra-rigid elements or mounting fixtures to combat the effect of high wind-pressures. Even the take-off thrust of a starling can have disastrous effects on an insecurely-mounted out-door aerial; and it is no fun (and rather humiliating) having to clamber over brittle tiles on a borrowed ladder to repair an aerial dislodged by so trivial an accident!

So put up your aerial indoors whenever you can. Given adequate lighting to show you what you are trying to do, you'll be able to erect it and maintain it in warmth and comfort for ever after. . . .

There is often no need for rigid aerial elements when you are putting up an indoor aerial. Appropriate lengths of coaxial cable stretched between two rafters and correctly orientated to the wanted signal will often serve as excellent dipoles, reflectors and directors; and the spacing between them can be brought close to the ideal $0{\cdot}1\lambda$ without fear of picture flutter being caused by wind. One essential precaution is to see that the rafters used are really *dry*, so that they can give adequate insulation.

If you decide to use rigid aerial elements after all, they can be mounted on a simple wooden boom, which will not rot or distort since it is not going to be exposed to the weather; and this boom is then easy to orientate towards the signal.



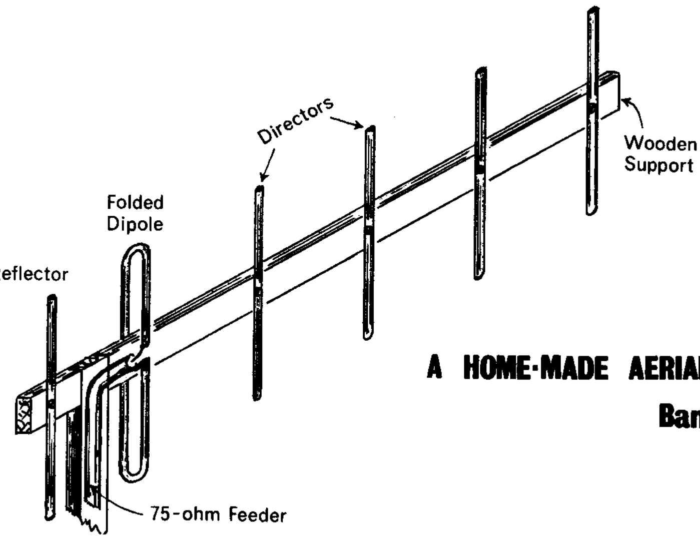
A DO·IT·YOURSELF
BAND 1 AERIAL

Of course, if you happen to have a horizontal rafter running in the right direction, you can fix your aerial elements to that and dispense with even the boom.

By and large, you can say that the stronger the signal from the transmitter reaching your attic, the less elaborate will your home-made aerial need to be. Never forget, though, that it is much better to have an aerial with too much gain than one with too little; so do not shrink from adding to your aerial further correctly-spaced elements of the correct length if you find that the picture you are getting is less good than it should be.

Home-Made Aerials (*continued*)

Pictured below is a simple home-constructed aerial which could be used to pick up transmissions in Band 3 and even (in particularly favourable circumstances) at the lower-frequency end of Band 4.



A HOME-MADE AERIAL:

Bands 3 & 4

All the elements which affect the performance of an outdoor aerial—signal frequency, distance from transmitter, height of aerial above ground, the presence or absence of hills, big buildings or large sheets of open water and so on—all these affect equally the performance of an aerial erected indoors. Additionally, the indoor aerial can be affected by the nature of the material forming the roof, and by metal guttering, water-pipes, storage tanks and chimney-stacks situated in the "wrong" direction from the aerial with respect to the path of the incoming signal.

Generally speaking, the comparatively long-wave transmissions in Band 1 are least affected by structural details of the house itself, but more care is needed in the siting of a Band 3 array. Try always to ensure that your aerial has an uninterrupted view towards the distant transmitter—assuming, as you normally can at VHF frequencies, that your roof itself is "radio-transparent".

At UHF frequencies, however, this last assumption is much less true; and it is only rarely that very favourable conditions make the erection of an indoor UHF aerial worth while. Luckily, the much smaller size and weight of these aerials make their erection out-of-doors a comparatively simple operation for the keen "do-it-yourself-er".

Remember that final adjustments to the mounting position and attitude of any aerial, indoor or outdoor, carried out on a trial-and-error basis, will often give you a better picture than the one you had to begin with. It will frequently happen that the aerial alignment giving you the *strongest* signal will not also give you the *best* signal, because the theoretically correct alignment may be the very one which makes the aerial most liable to pick up a strong interference signal.

Remember also, once you have decided on the correct alignment for your aerial, to try tilting the array up and down slightly to see if a more or less vertical (or horizontal, as the case may be) inclination will bring about a better picture.

Home-Made Aerials (*continued*)

If you are making your own aerial elements, they will need to be cut to the correct lengths. The formulae which follow will help you to do this. In them **f(MHz)** is the frequency of the desired signal in megaHertz; but this frequency can be either the frequency of the vision signal or the geometric mean of the frequencies of the sound and vision signals depending on the degree of importance you attach to maximum clarity of picture signal on the one hand, or to a good balance of sound and vision on the other.

❶ **Length of Dipole (in feet)** $= \dfrac{468}{f(MHz)}$

❷ **Length of Reflector (in feet)** $= \dfrac{498}{f(MHz)}$

❸ **Length of First Director (in feet)** $= \dfrac{450}{f(MHz)}$

Subsequent directors, as you know, should diminish in length by 5% of the length of their immediate neighbour nearer the dipole.

In the case of a folded dipole, dipole length is measured from the middle of the curvature at one end, round the unbroken side, to the middle of the curvature at the other end.

Last Words on Aerials

Aerials of the set-top type, which extend out of the top of a receiver like the antennae of a very large insect, are only useful in localities of high signal strength; for they can only be approximations to an accurately built and properly erected array. The advantage of receivers equipped with them is, of course, mobility, for there is no need to plug them into any feeder cable. But the price paid in impairment of picture signal is generally a high one.

Do not be surprised if you meet aerials whose performance in practice contradicts a certain amount of what you have learnt in this Section. There is, for instance, a Band 3 aerial erected on high ground near Tunbridge Wells which gives an acceptable picture of a BBC 2 programme without there being a UHF aerial of any kind on the roof. The Band 3 aerial is of quite the wrong electrical length to resonate to the UHF signal, and much of the latter's strength is inevitably dissipated by the standing waves set up along the dipole when the signal is received.

But the strength of the signal reaching the aerial is so great in this particular locality that it can produce a fair picture on the screen even after severe impairment. ("The signal we get from the Crystal Palace is so strong", says the owner with grateful overstatement, "that you could pick it up with a piece of wet string!")

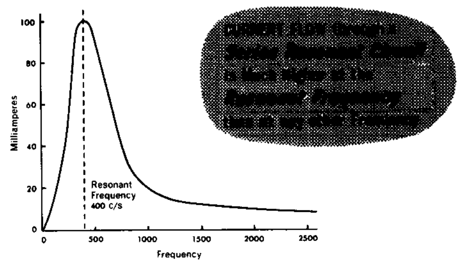
Aerial performance, in fact, varies with a good many factors, but by far the most important of them is signal strength at the point of erection. You have seen how widely this strength can vary at different points within the service area, especially at UHF. Do not be afraid, therefore, to experiment boldly if the officially "correct" rules fail to give you the results you hoped for when you are mounting a new aerial in a strange neighbourhood.

REVIEW of the Receiving Aerial

The task of a TV receiving aerial is to extract from the sound and vision signals of the desired transmission the energy required by the receiver to enable it to reproduce audibly the sounds uttered in the studio, and to display on the screen a satisfactory picture of the action taking place in the studio or elsewhere.

The aerial performs this task by responding to signal frequency. It responds well to all signals whose frequencies lie within the narrow band separating the sound and vision signals, but poorly to signals of all other frequencies.

An aerial is essentially a series-resonant circuit containing R, L and C. The current flow induced by a signal striking such a circuit is a maximum *when the signal is at the resonant frequency of the circuit.* Aerials can thus be made to resonate to signals of different frequency by changing the amounts of R, L and C in the aerial circuit.



The essential part of a TV aerial designed to pick up signals in the VHF range is a hollow metal rod some 12 or 13 mm in diameter whose length is equal to a little less than one-half of the wavelength of the desired signal. Such an element is known as a half-wave dipole.

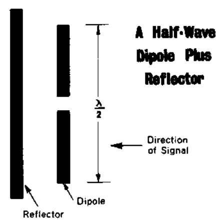
The distribution pattern of current and voltage along a dipole remains constant irrespective of the strength of the signal At either end of the dipole voltage is maximum but current minimum; and at *the centre of the dipole current is maximum* and voltage minimum. It is therefore usual for a dipole to be tapped for its energy at its centre point.

Two-Wavelength Dipole

Since a half-wave dipole is essentially a series-tuned circuit in which current flows under the impulse of alternating voltages, it must possess *impedance*. This impedance varies at every point along the dipole. It falls to an approximate value of 73 ohms at the centre of *any* dipole provided that the ratio of dipole diameter to dipole length is kept very small.

REVIEW of the Receiving Aerial *(continued)*

The receiving efficiency of a half-wave dipole is increased by the addition of a reflector and/or of one or more *directors*. These elements increase the ability of the dipole to pick up signals coming from a desired direction, so improving its directional properties.

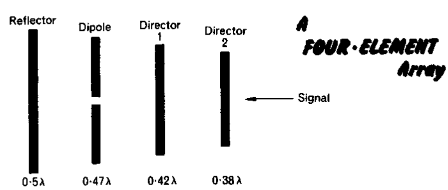


A reflector is a length of rod, usually a metal tube of the same diameter as the dipole but about 5% longer. Fixed between 0·15 and 0·25 of the wavelength *behind* the dipole with respect to the direction of the signal, it re-radiates some of the energy of the signal back to the dipole so that it arrives there *in phase with* the signal itself, and so adds to it. The degree to which the wanted signal is amplified in this way is termed the *power gain*, or *forward gain*, of the dipole-reflector combination.

The addition of a reflector also diminishes the response of the dipole to signals arriving from behind it with respect to the direction of the signal, and the *front-to-back ratio* of the dipole-reflector combination provides a measure of its improved response in a forward direction compared with its response in a backward direction.

The *director* is a length of rod about 5% shorter than the dipole, placed between one-seventh and one-eighth of the wavelength *in front of it* with respect to the direction of the signal. Its effect is to increase the directional properties of the dipole and to sharpen its frequency response.

Further directors may be added in front of the dipole to improve its performance still *more*. Each should be some 5% shorter than its predecessor. An aerial array containing a dipole, a reflector and a number of directors is called a *multi-element array*.



The addition of a reflector and/or directors to an aerial diminishes its centre impedance and so risks a mismatch with the feeder cable to the receiver, with its Z_0 of about 75 ohms. One way of reducing this danger is to fold the dipole over on to itself, and to tap it at the point where its ends nearly meet. The centre *Z* of a folded dipole is considerably higher than 75 ohms and so can stand reduction by the addition to the array of more aerial elements.

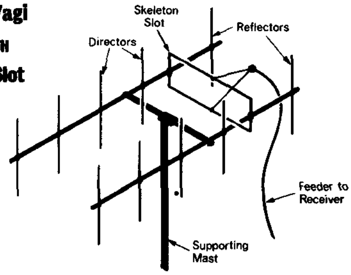
A multi-element array containing a folded dipole is often called a *Yagi aerial*.

The efficiency of an aerial will only be maximum if its orientation corresponds to the polarization of the wanted signal. An aerial must always be mounted vertically for best reception of a vertically-polarized signal, and horizontally for best reception of a horizontally-polarized signal.

REVIEW of the Receiving Aerial (*continued*)

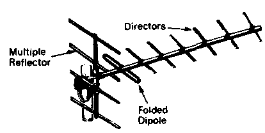
Other types of aerial used at VHF are the *slot*, the *folded slot* and the *skeleton slot*. All present problems of good matching to the characteristic impedance of the feeder cable; but once these have been overcome, slot-type aerials provide good forward gain combined with manageable size. A multi-element array consisting of a double Yagi and a skeleton slot aerial, designed to operate over three adjacent channels in Band 3, has excellent directivity and an overall power gain of the order of 16 dB.

A Double Yagi AERIAL WITH Skeleton Slot



UHF aerials need to produce a higher power gain than do VHF aerials because their $\lambda/2$ elements are shorter and so have lower signal-collection efficiency, because the signal reaching the aerial is often weaker, and because a stronger signal is nevertheless needed in the receiver to overcome the higher noise produced by valves operating at ultra-high frequencies. UHF aerials therefore need to be more elaborate; but the small size of their elements makes them easy to mount and maintain.

The need for high gain in UHF aerials is often met by adding several directors to specially designed reflectors. Examples of the latter are *four-element reflectors* and *wire mesh reflectors*.



UHF Aerial WITH REFLECTOR

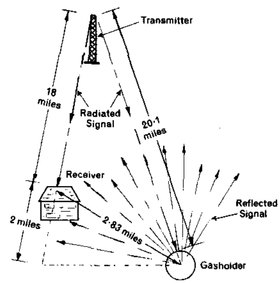
Another type, the *corner reflector* aerial, makes use of a folded dipole with no directors. It gives good forward gain.

All British UHF aerials are designed to have a nearly even frequency response over the wide bandwidth of 88 MHz, to make them capable of receiving all the four UHF programmes planned for every viewing area.

Methods of giving them the broader *acceptance bandwidth* made necessary by this decision include increasing their diameter relative to their length, and the *conical*, *simulated conical* and *bat-wing* types of dipole.

REVIEW of the Receiving Aerial (*continued*)

Television *ghosts* are seen on the picture screen when the signal is received by the aerial twice—once direct from the transmitter and again, a few microseconds later, after being reflected from a large object like a gas-holder. If these two signals arrive in phase with one another, the ghost will be a *positive* one; if they arrive out of phase, it will be *negative*.



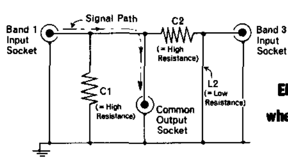
UHF aerials, with their greater directivity (narrower *acceptance angle*), are less liable to pick up ghosts than are VHF aerials, provided they are mounted rigidly and securely. Ghosts can often be "exorcised" by turning the aerial array slightly away from the transmitter in a direction unfavourable to the ghost signal.

***Aerial feeder cables* are usually of the coaxial type, and are made with a characteristic impedance of about 75 ohms. *It is essential to ensure that the impedance of the dipole at the point where it is tapped to the feeder is also about 75 ohms,* for a mismatch will result in part of the signal being lost in the feeder on its way to the receiver.**

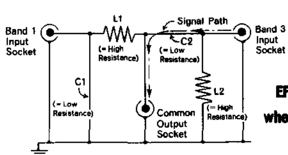
Methods of preventing a bad mismatch include the *T-matching* and *delta-matching* techniques, and the tapping of a *unipole* at one of its ends with the aid of a quarter-wavelength stub.

The *diplexer* is a device for feeding into a common socket signals of different frequency while keeping each signal out of the aerial circuit of the other and so upsetting its characteristic impedance. It consists essentially of a *high-pass filter* plus a *low-pass filter*.

By the addition of a *band-pass filter*, the device becomes a *triplexer*, which can be used for passing the signals derived from three aerials into a single feeder, or *vice versa*.



EFFECTIVE DIPLEXER CIRCUIT
when a Band 1 signal arrives



EFFECTIVE DIPLEXER CIRCUIT
when a Band 3 signal arrives

§11: THE TUNER

The tuner is the first major component which the incoming signal from the aerial encounters after it enters the receiver.

It is also the most important component in the entire receiver. Practically any other stage in the receiver can be working "below par", and you will probably get a picture of sorts on your screen. But if the tuner is wrong, you will get nothing intelligible at all.

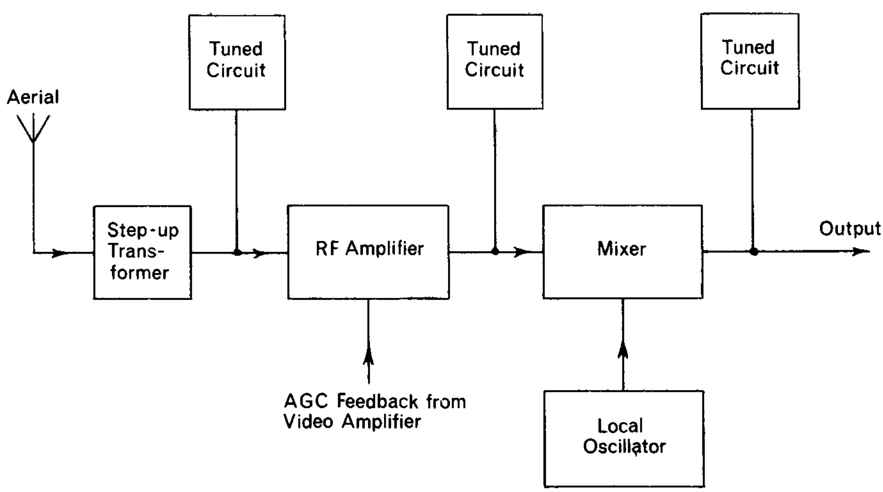
For reasons which you will see, the tuner has to be kept well away from the other components in the receiver. In the Dual-Standard Set, the oblong metal boxes containing the two tuners (VHF and UHF) are situated in the receiver chassis directly behind the *Channel Selection* knob on the front panel. The box containing the VHF tuner is always the bigger of the two.

Because of the different order of electronic problems raised by frequencies in the UHF range, the two tuners need to be quite different; but there is some use of circuits in the VHF tuner to help out with special difficulties encountered in the UHF tuner.

The function of the tuner is, of course, common to both systems. It is to *select* the sound-and-vision signal required by the viewer from the group of such signals present in the channel covered by the aerial; to *raise the amplitude* of this signal to a usable level well above the inherent noise-level of the receiver; and to *convert* the sound and vision frequencies of the signal into the intermediate sound and vision frequencies of the receiver.

(The tuner section of a TV receiver, by the way, also has an unofficial name. It is often known simply as "the front end".)

Begin, now, with the *VHF Tuner* used in the British Dual-Standard Set, and look at a simple schematic diagram of the blocks which go to make it up.



BLOCK SCHEMATIC of the VHF TUNER

The VHF Tuner

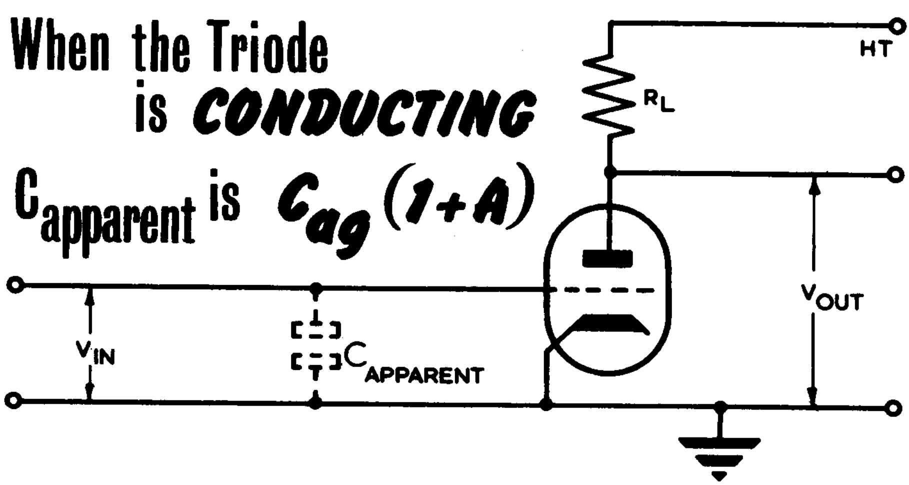
The first stage in the VHF tuner is a small step-up transformer whose function is to raise to a more usable level the voltage of the very faint signal coming through the coaxial cable from the aerial. The stepped-up signal is then passed through a tuned circuit to the second, more important stage, the r.f. amplifier.

The function of the **r.f. amplifier** stage is to raise the amplitude of the wanted signal to a level high enough to make it usable after it has been mixed with the signal which will be applied to it from a local oscillator in the next stage. What sort of valve can be used for this amplification?

The obvious type to try would seem to be a pentode, whose amplification factor you know to be high and whose anode-to-grid capacitance is very small. Unfortunately, however, the number of electrodes contained within a pentode cause it, at the high frequencies used in TV, to generate an amount of electrical noise which is often great enough to obliterate the wanted signal altogether.

A triode, which has a much lower noise factor, has to be used instead; but it too has disadvantages. Not only is the gain of a triode at high frequencies poor. It also has an anode-to-grid capacitance which, when the valve is operating at high signal frequencies, can become large enough to stop the valve acting as an amplifier at all, making it burst into oscillation instead.

For a fuller explanation of the **Miller Effect** by which this phenomenon is caused, you are referred to pages 2.43 and 2.44 of *Basic Electronic Circuits*. What happens, briefly, is this. You know (*Basic Electronics*, Part 2) that the anode-to-grid capacitance—C_{ag}—of a triode causes feedback of voltage from the anode to the grid, and so makes it appear as if the anode load is affecting the input impedance of the valve. This change in input impedance is much increased once the triode starts to conduct—the *effective* value of the C_{ag} of the valve becoming $1+A$ times its physical value, where A is the voltage gain of the valve.

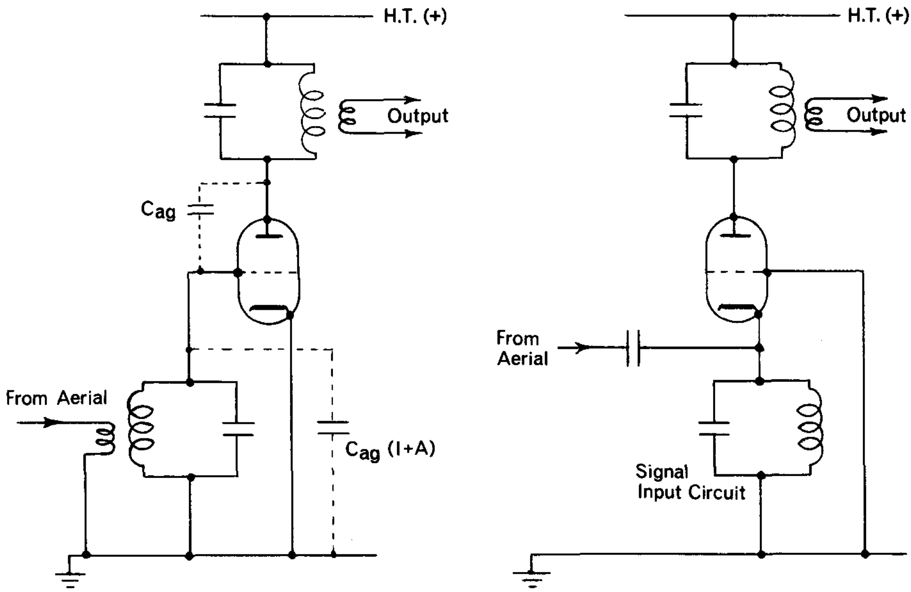


With a multiplier of this order at work, the amount of voltage fed back to the grid soon becomes so large that the valve bursts into oscillation, and ceases to amplify at all.

The VHF Tuner—The Cascode Amplifier

The range of frequencies over which a triode can be used as an amplifier can be largely extended by earthing its grid, and by applying the signal to its cathode instead. The grid now acts as an earthed screen between anode and cathode. Capacitive coupling between anode and grid, and therefore the risk of instability, is thus almost completely removed.

The illustration below shows the different connections of a normal triode amplifier with its cathode taken to earth, and of the so-called *grounded-grid* configuration described above.



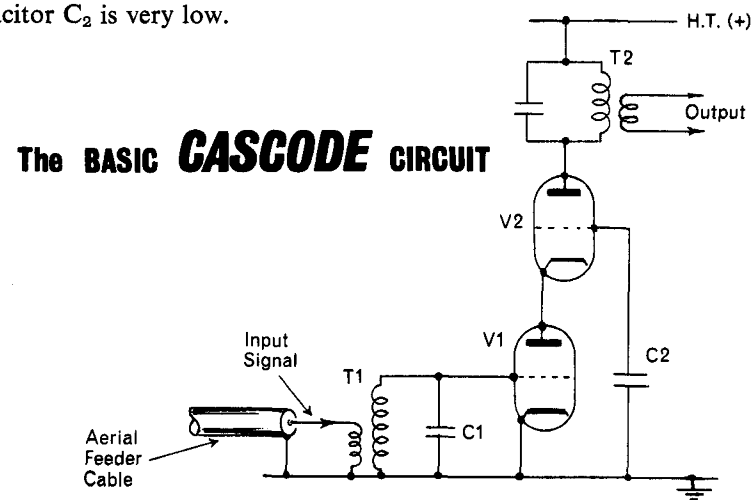
The GROUNDED-CATHODE Amplifier **The GROUNDED-GRID Amplifier**

Here again, however, an apparent remedy develops its own disease, and turns out to be only a step on the way to a cure. When a valve is connected as a grounded-grid amplifier, its anode current must flow through the signal source, since this is connected in series with the cathode. The result is a very low input impedance, which causes serious damping of the signal and loss of sharpness of tuning. Both the frequency response and the gain of the valve are reduced, and selectivity becomes poor.

A solution has been found by using *two* valves in the r.f. amplifier stage of the VHF tuner, connected in such a way that the resulting circuit combines a high input impedance with the ability to amplify signals having a high operating frequency. Such a circuit configuration is called a *cascode*. Until quite recently, cascode amplifiers have dominated the design of VHF tuner circuits; and they are still widely used in sets of British design.

The VHF Tuner—The Cascode Amplifier (*continued*)

The cascode amplifier consists essentially of an ordinary (grounded-cathode) triode—having another triode connected, *in the grounded-grid configuration*, as its anode load. In the circuit below, the grounded-cathode valve is V_1. V_2, its anode load, has its grid effectively earthed (as far as the signal is concerned) because the reactance of the capacitor C_2 is very low.



The circuit arrangement of V_1 gives it a high input impedance, thus matching it with the signal reaching it from the step-up transformer T_1 connected between the coaxial feeder from the aerial and the valve. The secondary of T_1 is tuned (by C_1 and the input capacitance of V_1) to the frequency of the desired signal, and therefore behaves as a parallel resonant circuit. An input circuit of such a type gives an increase in signal amplitude, often of the order of 1:5.

You know that the gain of an amplifier is increased as its anode load is increased. Here, the anode load of V_1 is the input impedance of V_2, which is always low and usually less than 200 ohms. The gain of V_1 is therefore low—but because of this low gain, *the valve remains stable.* A higher gain would give a correspondingly high value to the "Miller" coupling between its anode and its grid, and the valve would cease to amplify and would burst into oscillation instead.

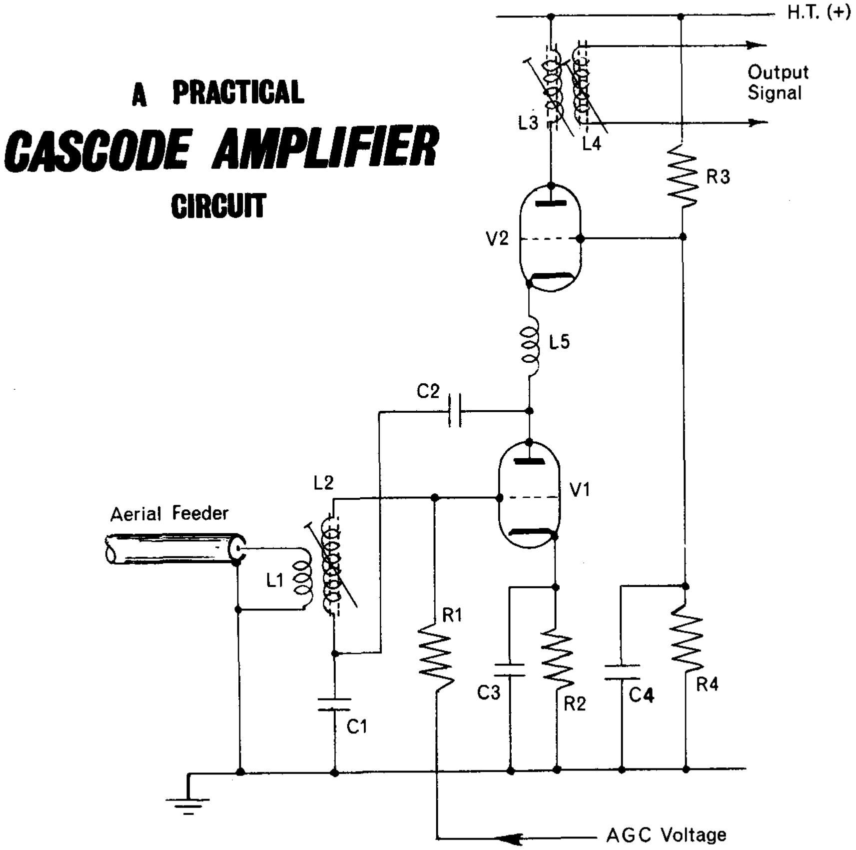
The function of V_1 in the cascode circuit is therefore not to provide gain in the normal way of an amplifier, but to act as an impedance multiplier. This high impedance makes it possible to connect the cascode direct to T_1 (which itself, as you have seen, provides a 1:5 step-up in signal strength at V_1 input).

A further advantage of the high impedance offered by V_1 is that it improves the selectivity of the cascode by lessening the damping effect on the input signal of the low impedance of V_2.

V_2 in the cascode acts as a normal grounded-grid amplifier, amplifying the signals fed to its cathode from V_1. Its anode load, which is always made high to give it good gain, is a parallel-tuned circuit designed to resonate at the same frequency as the tuned circuit (T_1 secondary–C_1) connected to the grid of V_1. This arrangement ensures that the impedances of the two tuned circuits, and therefore the overall gain of the cascode, are maximum *only* at the signal frequency to which the two circuits are made to resonate.

The VHF Tuner—A Practical Cascode Amplifier

A practical cascode amplifier contains a number of additional components compared with the basic circuit you have just learnt about. Pick them out on the circuit diagram below as you read the account of their functions which follows.



1 L_5 is a coil connected in the anode circuit of V_1, and acts as a *peaking coil.* It is put in to compensate for the progressive loss of gain which an amplifier suffers as frequency rises beyond a certain point. In conjunction with the input capacitance of V_2 and the stray capacitances which are always present at this point in the circuit, L_5 forms an effective parallel-tuned circuit.

The frequency to which this tuned circuit is resonant is slightly higher than the highest frequency of the signal to which the two transformers (L_1–L_2 and L_3–L_4) are tuned. This arrangement serves to improve the frequency response of the circuit as a whole.

2 C_2, in conjunction with C_1, acts as a *neutralizing capacitor*, and is inserted in order to nullify the dangerous C_{ag} of V_1. Connected between V_1 anode and the lower end of the coil L_2 in the tuned circuit of V_1 grid, it feeds back to the grid a signal equal in magnitude, but opposite in phase, to the signal fed-back through the C_{ag}. The two signals thus cancel one another out, and the stability of V_1 is greatly increased.

The VHF Tuner—A Practical Cascode Amplifier *(continued)*

3 R_2 and C_3 are the normal components used to deliver bias voltage to the cathode of V_1. Bias for V_2 is derived from the potential divider circuit R_3–R_4, which is connected across the HT supply. The values of R_3 and R_4 are so chosen that the positive voltage developed across R_4 will always be *less* positive than the voltage at V_1 anode. This latter voltage is always positive, and is always the same as the voltage at V_2 cathode. Thus the *less* positive voltage applied from the biasing circuit to the grid of V_2 keeps the grid biased *effectively negative with respect to its cathode.*

C_4 is the grounding connection for earthing the a.c. signal on the grid of V_2.

4 The negative AGC voltage is, as you know, fed back to the VHF tuner from a later stage in order to keep constant the overall gain of the receiver whatever changes occur in the input signal. This voltage is applied to the grid of V_1 through the resistor R_1. The capacitor C_1 serves as a blocking capacitor to isolate the AGC voltage from earth, as well as forming part of the tuned circuit of V_1 grid and of the neutralising circuit with C_2 described above.

5 The output of the cascode is taken from the transformer tuned circuit (L_3–L_4) in the anode of V_2. This circuit is tuned to resonate at the same frequency as the transformer tuned circuit (L_1–L_2) in the grid of V_1. L_2, L_3 and L_4 have adjustable metal cores so that the two tuned circuits can be correctly set up during initial alignment by the manufacturer.

Brass or iron dust is used for the cores of inductors handling frequencies in Band 1. Brass is usual for the handling of frequencies in Band 3.

Summing Up the Cascode

The purpose of the cascode amplifier is, first and foremost, to remain *stable*, while raising the amplitude of a high-frequency signal to a level which makes it usable in the mixer stage which immediately follows it, without equally raising the level of its accompanying noise. High-frequency signals are not easy to amplify at all, and the gain of a cascode is typically only about ten times. Real amplification of the signal is only attempted after it has been reduced to a much lower intermediate frequency.

Note that the cascode has been shown in the circuit diagram in this Section as two separate valves. In practice, these two valves are always contained within a single glass envelope.

Frame Grid Valve Construction

It was primarily the limitations of the conventionally-built cascode, and of other types of valve also tried out in the tuner stage of TV receivers, which led to the introduction of a type of valve construction somewhat different from those you have met so far. The new type has proved so valuable that nowadays almost every valve intended for use in HF applications, including pentodes and the latest types of UHF triode, is built in this way.

Valves built on the **frame grid** principle, as it is called, look from the outside much like any other valve, and they function in exactly the same way. The construction of one of the electrodes in them is, however, different; and you must now see how it is done.

Frame Grid Valve Construction (*continued*)

The problem which needs to be overcome is this. The overall amplifying ability of any valve depends, as you know (*Basic Electronics*, page 2.21), largely on its *mutual conductance* (G_m). The higher the G_m, the greater the amplification of the valve.

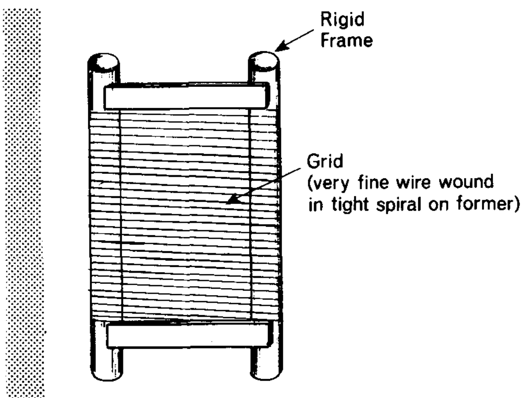
It is possible to get high values of G_m in a valve by positioning the control grid very close to the cathode, so that it has maximum influence on the electron stream. Unfortunately, the closer the grid and the cathode are brought together, the greater the capacitance (C_{gk}) between them—and a high C_{gk} means a low input impedance to the incoming signal. The result is poor amplification—and back you are where you started.

In the frame-grid type of valve, the advantages of close grid-to-cathode spacing without the disadvantages of increased C_{gk} are obtained by constructing the grid of extremely thin wire—no more than 10 microns in diameter. (A *micron* is one thousandth of a millimetre, or about 1/25th of one thousandth of an inch.) The grid is then positioned only 50 microns away from the cathode.

The fact that the grid is not a continuous plate but rather an array of very thin wires separated from one another by an air gap greatly diminishes the capacitance between grid and cathode, despite the fact that the latter is positioned only some 0·05 mm. away.

With such close spacing, however, it is vital to keep the grid wire structure rigid. Otherwise, small variations in the spacing (caused, *e.g.*, by temperature changes or mechanical shock) could bring about large changes in anode current.

Rigidity is achieved by winding the grid wire under tension in a spiral round a thick and sturdy frame. It is this frame which gives the type of valve its name.



FRAME GRID Valve Construction

Grids constructed in this way can be substituted for the normal control grid in any type of valve—triode, tetrode or pentrode—and greatly increase their amplifying efficiency. For example, a TV receiver having frame-grid valves in the cascode and frequency-changing stages of the tuner, and serving as the first valve in the i.f. amplifier, will have an overall gain factor eight times that of a receiver using conventionally constructed valves. A typical value for the G_m of a frame-grid triode used in a VHF tuner is 12·5 mA/V, compared with only 6 mA/V for conventionally constructed triode.

The increased gain factors made possible by frame-grid construction have done much to improve the performance of TV receivers in areas of poor reception.

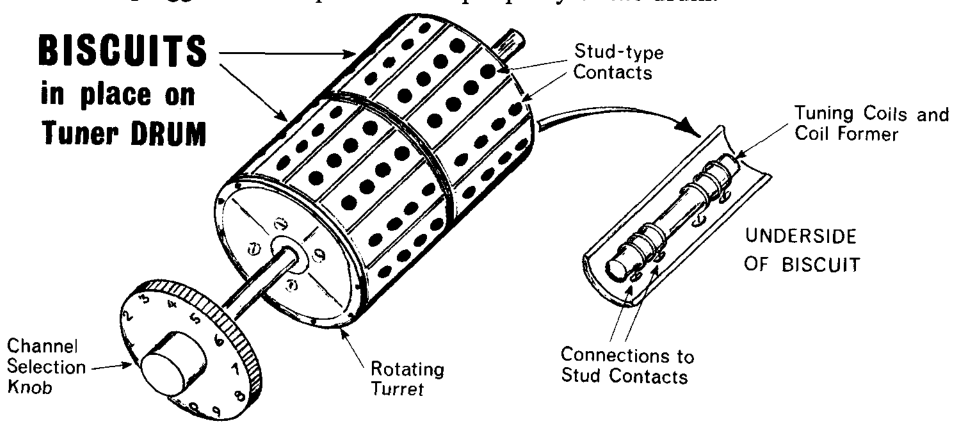
The VHF Tuner—Channel Selection

The next problem arises when the viewer wishes to connect his set to an aerial in a part of the country where the programme he wants to watch is radiated on a frequency different from that on which he has watched it hitherto. How can he switch his set to receive signals in a different frequency channel without having to alter important physical components inside his receiver?

The difficulty arises from the fact that, every time the viewer switches to a different channel, the resonant frequencies of three important components in the tuner need to be changed in order to conform to the different resonant frequency of the new aerial. (Remember that an aerial of different length is required for good signal reception in every different channel, because every channel carries a different range of wavelengths and because aerial length must always be close to one-half of the wavelength of the signal which the aerial is to receive. The three components needing to be changed are the tuned circuits in the grid and in the anode of the cascode amplifier, and the local oscillator in the mixer stage (which you will be learning about shortly).

There are a number of ways of bringing about the required changes of resonant frequencies. Most British makers prefer a technique whereby a different set of inductor coils, each pre-aligned for one of the 13 different resonant frequencies required, is physically connected into the circuitry of the tuner every time the viewer switches to a different channel. The technique by which this is done is known as **turret tuning.**

In turret tuning the complete set of coils required for each separate channel is mounted on the inside of a piece of insulated material shaped as a one-thirteenth segment of a hollow *drum*. Each of these segments is individually known as a *biscuit*, and can be plugged into its place on the periphery of the drum.



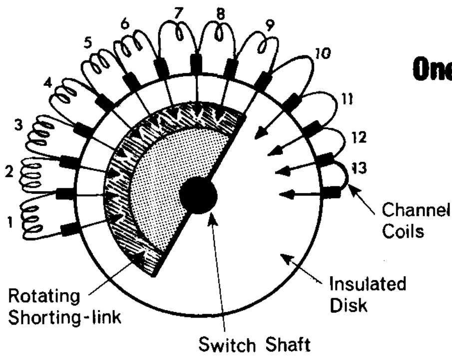
The connecting leads to every set of coils are taken through the insulated material of the biscuit on which they are mounted to a pair of contact studs on its outer surface. Rotation of the drum is effected when the viewer operates the *Channel Selection* knob on the face of his TV receiver. Every click of this knob moves a different biscuit into position inside the tuner, and thirteen clicks make up one complete rotation of the knob. The turret tuner thus works on the same principle as does the bullet-holding chamber of a revolver.

When a particular biscuit is moved into the working position in the tuner, the contact studs on its outside surface are connected into the circuitry of the tuner through a set of wiper contacts of the spring-leaf type fixed on the tuner chassis, which "make" with the contact studs of the biscuit. There being only one set of wiper contacts, only one set of coils can be connected into the tuner circuits at any one time.

VHF Tuners—Channel Selection (*continued*)

Another method of changing the resonant frequencies in a VHF tuner is called **incremental tuning.** Though less used than the turret type, it is exclusively employed by some British manufacturers.

The incremental tuner is a variable inductor in which a rotary switch is moved to short out unwanted parts of the total inductance. A number of coils, wired together in series, are mounted round the periphery of flat disks called *wafers* or *banks*. There are a number of these banks fitted on top of one another like a layer-cake, one for every section of the tuner (aerial, r.f. amplifier, oscillator, etc., circuits) which needs adjustment during the tuning process. All the banks are mechanically linked to the operating shaft of the switch so that when the *Channel Selection* knob is rotated by the viewer, all move round together.



One Bank of a VHF INCREMENTAL TUNING SWITCH

When Set is switched to Channel 10
—Coils 1–9 are shorted-out
—Coils 10–13 are in-circuit

The inductance value of every coil mounted round every bank of the switch is chosen with care. When the tuner is required to operate on the lowest channel frequency (Channel 1, 45 MHz vision), the value of inductance required in the various stages needing adjustment is high. All the coils in every bank are used, and their individual values of inductance are added together and connected in series to a larger inductor, of fixed value, which is not affected by the switch and which provides the greater part of the total inductance required. There is a separate fixed inductor, of course, for every bank of the switch.

When a lower value of total inductance is required (say when the tuner is being set to operate on the highest channel frequency—Channel 13, about 215 MHz vision), all the coils save one on every bank are shorted-out, so that very little is added to the value of the fixed inductor for that setting.

At the low-frequency side of every wafer, the inductors are small coils of wire thick enough to need no other support. Towards the high-frequency side, straight (or only slightly bent) pieces of wire connected between the switch tags are sufficient to provide the small values of extra inductance required.

Although the incremental-inductance type of tuner is simpler in construction than the turret, and so generally cheaper, it has a number of disadvantages. One is the large number of switch contacts required, especially in the higher frequency channels where many unwanted inductors need to be shorted out. Dirt on the surfaces of any of these contacts can cause trouble.

Another disadvantage is the difficulty of alignment. Individual coils cannot be adjusted for inductance value without affecting the rest of the inductors, since all are connected in series. This means that the coils have to be carefully manufactured so as to have precisely the required values of inductance. Once they have been fitted, further adjustment to them is a matter for expert attention.

The VHF Tuner—Lowering the Frequency of the Wanted Signals

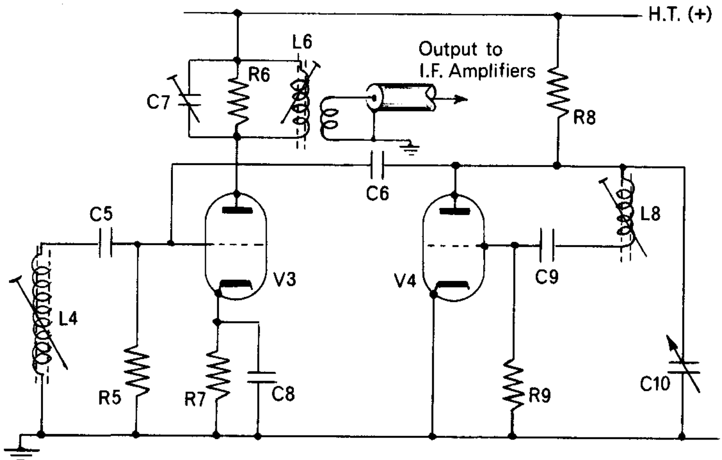
Once the channel has been selected in this way, the sound and vision signals in it are amplified to a usable level by the cascode valve in the r.f. amplifier, and then fed to the **frequency changer** for conversion to a lower frequency.

The frequency changer consists of two valves—a *local oscillator* which is a triode, and a *mixer* valve which is a pentode. In the majority of British VHF tuners, the two are contained within a single glass envelope.

Mixing is done according to the normal superheterodyne principle you learnt about in Part 5 of *Basic Electronics*. The output is two still-separate sound and vision signals each carrying the amplitude modulation bearing the desired information, but both on *intermediate frequencies* low enough to make possible all the amplification needed in later stages of the receiver.

The circuit diagram of a typical VHF frequency changer stage looks like this:

The FREQUENCY CHANGER Circuit in the VHF Tuner



The local oscillator in the circuit above is the triode V_4. This functions as a Colpitts oscillator of the type you learnt about on *Basic Electronics*, page 3.63, and makes use of its own interelectrode capacitances to resonate with the variable inductor L_8. HT is supplied to V_4 through R_8, being prevented from reaching the grid of the valve by the capacitor C_9. The valve is self-biased by the components R_9 and C_9—the latter thus performing a second useful function.

Since it is necessary for the mixer stage to produce the same intermediate-frequency signals whatever the frequency channel over which the viewer wishes the tuner to respond, the operating frequency of the local oscillator needs to be altered every time the channel is changed. (Remember that the intermediate frequency required is the resultant when the sound or vision signal frequency is *deducted* from the frequency of the local oscillator. The L.O. frequency must therefore be kept above signal frequency by a constant amount.)

The VHF Tuner—Lowering the Frequency of the Wanted Signals (*continued*)

The frequency of the local oscillator is changed at the same time as the tuning coils are changed, by the viewer manipulating the *Channel Selection* knob on the outside of his receiver. If incremental tuning is being used, the change of frequency is achieved by varying the value of the inductance L_8. With the turret tuner, it is achieved by physically changing this inductor for one of a different value.

This gives coarse control of L.O. frequency. Fine control is achieved when the viewer rotates another knob on the face of his receiver, generally mounted with its shaft concentric with that operated by the *Channel Selection* control so that the two appear to operate through the same shaft.

This *Fine Tune* control is achieved by adjusting the value of the variable capacitor C_{10}, which is connected in parallel with V_4. This capacitor, which is of very small capacitance, is effectively in parallel with the C_{ak} of V_4 and thus forms part of the tuned circuit of the oscillator.

Fine tune control can, of course, be used by the viewer to correct for frequency drift within a given channel, as well as for final tuning after the channel is changed.

The signal produced by the local oscillator is generally injected on to the control grid of the pentode mixer valve V_3 through the low-value capacitor C_6 (though you will come across other arrangements which rely either on the self-capacitances between the two valves, or on the mutual inductance between the inductors L_8 and L_4 when placed physically close to one another in the tuner).

The channel signal reaches the control grid of V_3 through C_5, and superheterodyne action follows. R_7–C_8 form the normal cathode-biasing arrangement for V_3, and R_5 is its grid leak. The anode load of V_3 is the transformer stage C_7–R_6–L_6–L_7.

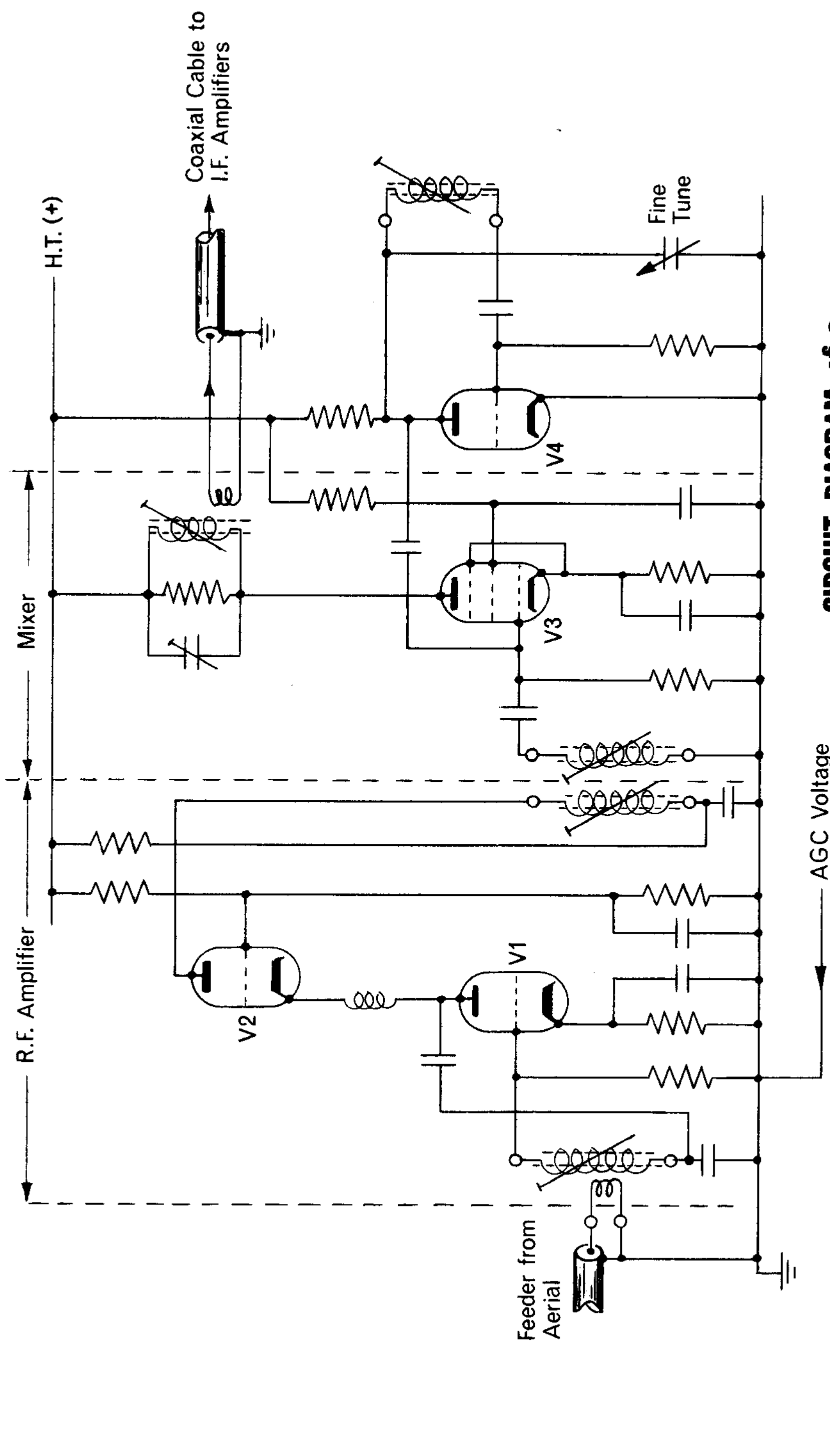
Among the many intermediate frequencies produced by the mixing process in V_3 are the two frequencies which the viewer wants—namely, the i.f.'s of the sound and vision signals he is looking for. The resonant circuit L_6–L_7 is broadly tuned to these i.f.'s, and ensures that the degree of amplification which the mixer valve additionally produces is applied only to the two wanted frequencies. This broad tuning is achieved with the aid of the damping resistor R_6, connected in parallel with the coil, which broadens the frequency response of the tuned circuit by introducing a resistive loss.

The two intermediate frequencies required are fed to the main i.f. amplifier stages in the next section of the receiver through coil L_7, which is loosely coupled to L_6 in such a way as not to alter either the resonant frequency or the loading of the latter.

The intermediate frequencies at present used for 405-line reception in Bands 1 and 3 are **34·65 MHz** for the vision signal and **38·15 MHz** for the sound signal. With the local oscillator frequency kept above both these frequencies so that the two i.f.'s are obtained by deduction from it, the 45 MHz frequency of the vision signal in Channel 1 of Band 1 calls for an L.O. frequency of (45+34·65=) **79·65 MHz.** This oscillator frequency produces an i.f. of 38·15 MHz from the sound carrier by deduction from it of the sound carrier frequency in Channel 1 of 41·5 MHz.

Note that the two i.f.'s (34·65 MHz for vision and 38·15 MHz for sound) are still 3·5 MHz apart, but that their relative magnitudes have been inverted. The sound frequency is now the higher of the two, whereas before mixing the vision carrier frequency (45 MHz) was 3·5 MHz above the sound carrier frequency (41·5 MHz). This inversion always occurs when the local oscillator is operated *above* signal frequency.

The Complete VHF Tuner



CIRCUIT DIAGRAM of a

Complete VHF Tuner

The UHF Tuner

The function of the UHF tuner is exactly the same as that of its VHF counterpart: namely, to select the required signal from the many other signals contained in the channel covered by the aerial, and to convert the sound and vision frequencies of this signal into the two intermediate frequencies needed by later stages in the receiver. Because of the extremely high frequencies over which the UHF tuner has to operate, however, the VHF techniques which you learnt about earlier in this Section will not work; and something quite different has to be adopted instead.

The main problem which arises in UHF tuning is that at ultra-high frequencies the ordinary *LC* tuned circuit will not work. For reasons which you will have to accept on faith until you have done a good deal of work on microwave theory, at UHF most inductors and most capacitors develop a distressing tendency to behave like their opposite numbers (capacitors behaving as inductors, and *vice versa*). Such components would work properly at these frequencies only if they were so minutely small as to be practically incapable of manufacture.

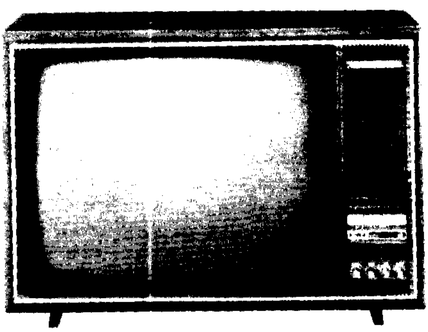
Before you consider how to set about overcoming these difficulties, it is worth taking a brief look at the nature of the practical problem which has to be solved.

Bands 4 and 5, over which Britain's 625-line programmes are transmitted at UHF, are divided into 48 channels numbered from 21 to 68, each having a channel width of 8 MHz. Band 4 contains 14 channels (Nos. 21 to 34), and extends over a frequency range from 470 to 582 MHz. Band 5 contains 30 channels (Nos. 39 to 68), extending over a frequency range from 614 to 854 MHz. Channels 35 to 38 are reserved for non-TV use.

Every transmitting station is allotted four channels, not consecutive but generally spaced three or four channels apart. No station at present uses all of its four channels, but all will eventually do so as additional 625-line programmes are introduced.

If a TV receiver is to remain in a single area of the country all its working life, its UHF tuner will therefore never be required to operate over more than four channels—and with very few stations will the maximum frequency range it has to cover exceed 88 MHz. For this reason, a good many UHF tuners are of the push-button type, covering four channels only. This makes them easy to tune by the non-expert; but if their owner takes them to another part of the country served by different channel frequencies, they will not work in the new area until all their channel coils have been replaced.

Another type of UHF tuner is continuously variable, and is capable of tuning over all the available UHF channels. The required channel is "tuned in" by operation of a slow-motion control, which is carefully rotated until the number of the channel sought appears on a numbered dial.

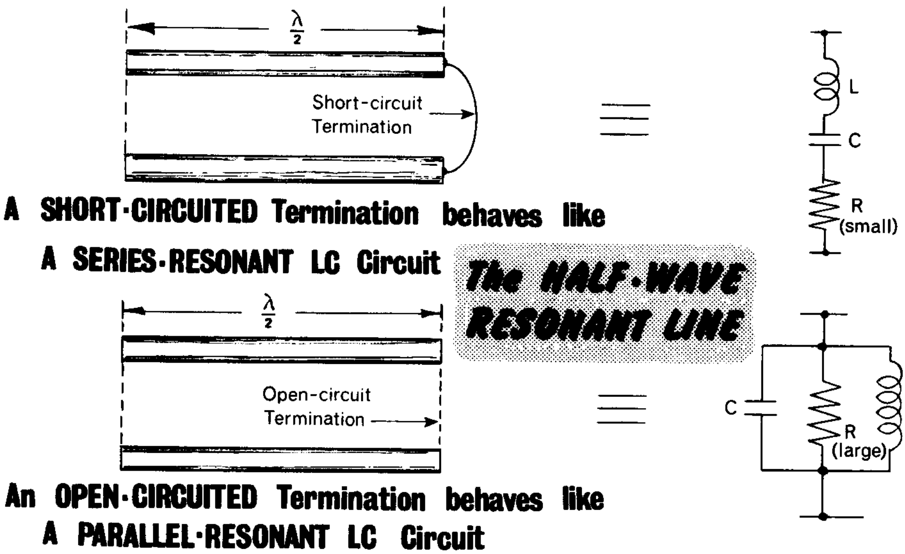


A Receiver with PUSH-BUTTON TYPE Tuning

The UHF Tuner—Resonant Lines

You have seen that the ordinary *LC* tuned circuit will not work properly at UHF because at these frequencies most inductors and most capacitors cease to behave as they do at lower frequencies. What can be found to take their place?

Recall at this juncture what you learnt about *resonance in mis-matched transmission lines* in Section 5 of *Basic Electronics*, Part 4. A resonant line, you found, is a section of a transmission line consisting of two parallel wires, which can be made to behave either as a series resonant circuit (having low resistance) or as a parallel resonant circuit (having high *R*) depending on its length and on the nature of its termination. Given a section of line whose electrical length is exactly one-half of the wavelength of the transmission being passed through it, the section will behave as a *series-resonant* circuit when its termination is a *short circuit*, and as a *parallel-resonant* circuit when its termination is an *open circuit*.



Now the grid and anode circuits of the cascode amplifier are both parallel-resonant, so both could seemingly be replaced by half-wavelength resonant circuits having open-circuit terminations. But that solution itself raises two difficulties. First is the problem of how to alter the physical length of the straight lines of wire forming the resonant circuits every time the wavelength of the required signal varies. At the bottom end of Band 4, at 470 MHz, the wavelength is about 635 mm. At the top end of Band 5, at 854 MHz, it is a little less than (356 mm).

The second difficulty is that it would be exceedingly inconvenient to have to fit into the TV receiver a number of straight and parallel lengths of wire (if that be the solution tried for the first difficulty), of which the longest would have to be half the length of the longest wavelength in the two Bands. You have just seen that this is some 635 mm; so the corresponding resonant line would have to be about 318 mm long. This would make the physical size of the screening box in which the tuner section has to be encased unacceptably large; so some other solution must be sought.

Fortunately the resonant line has another property which can be used to overcome the problem.

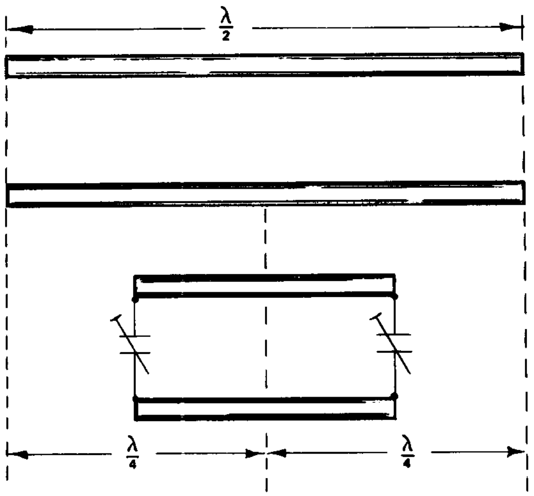
The UHF Tuner—Resonant Lines (*continued*)

You learnt on page 4.54 of *Basic Electronics* that between the open-circuited end of a transmission line and a point one-quarter of a wavelength back from the open circuit, the impedance of the line is capacitive. In other words, any length of open-ended line whose length is *less* than one-quarter of the wavelength being transmitted behaves as if it were a capacitor.

So why not simply substitute a capacitor for an appropriate length of the line, and see if it won't do just as well?

The longest wavelength to be handled in Bands 4 and 5 is about 635 mm. The corresponding half-wave resonant line is about 318 mm, and is (as you know) inconveniently long. But a quarter-wavelength is all of 150 mm—and if you snip off a bit rather less than 150 mm long *from each end of the half-wave resonant line* and connect a capacitor of the correct value in the place of each bit snipped off, you have a line behaving just as it did before—but now only some 30 to 40 millimetres in length.

Moreover, capacitors have the great advantage over bits of parallel transmission lines that they can easily be made variable. So if you fit *variable* capacitors in place of the snipped-off bits of line, you can vary the effective (electrical) length of the now-very-short resonant line so that it can be tuned to operate over a wide band of frequencies.



How the Physical Length of a Half-Wave Resonant Line is Shortened

The usual method of tuning a UHF tuner thus employs a four-gang variable capacitor operated by the viewer from the front panel of the receiver through a chain of high-reduction gearing linked to the *Channel Selection* dial. Each gang of the capacitor is connected across the termination of a resonant line in one of the five screened compartments into which (as you will see in a moment) the UHF tuner has to be divided up. The value of capacitance of all the gangs can be made such that the lines which they terminate are resonant at any frequency between 470 MHz (the lowest frequency in Band 4) when the gang is set to maximum capacitance in Channel 21, and 854 MHz (the highest frequency in Band 5) when the gang is set to minimum capacitance in Channel 68.

It is normal to find small-value trimming capacitors also connected at either end of the lines for use by the manufacturer in his initial alignment of the tuner.

The Need for Screening in the UHF Tuner

You have already seen that serious problems of component behaviour arise at ultra-high frequencies, such as you have not met in any of your earlier work on electronics. This is especially true when you are handling frequencies in Band 5, which can be as much as four times higher than the highest VHF frequencies encountered in Band 3.

At UHF even a straight piece of wire develops a significant inductance of its own, which makes it impossible to wind coils in the usual way. The values of capacitance to which a UHF circuit responds are so small that the mere proximity of another UHF circuit is often sufficient to produce a capacitive coupling between the two. This coupling can be deliberately put to good use in the design of a UHF circuit, but it can also be a nuisance which has to be guarded against.

Yet again, signals of very high frequency can also cause feedback of oscillator radiation from the tuner to the aerial, from which they could be re-broadcast to the detriment of other viewers. This back-radiation from the UHF tuner is the subject of stringent international control, and it is an important secondary function of the r.f. amplifier to isolate the frequency-changer stage in the UHF receiver from the aerial.

For all these reasons, one of the paramount requirements in the UHF receiver is that **screening** arrangements must be effective—and the stage in which they are most needed is the tuner, where the frequencies handled have yet to be dropped to the i.f. level.

As you know, the tuner stage itself is commonly screened from the other circuits in the receiver by being enclosed in a metal box of its own, placed well away from the other circuits. But many of the circuits inside the tuner stage itself also need screening from one another. This is generally done by dividing up the metal box of the UHF tuner into a number of separate compartments, each having special feed-through arrangements into its neighbours, and each containing only those components or stages which will not have undesirable reactions on one another when they are at work.

A typical arrangement is the Mullard Ltd. design illustrated opposite. The tuner circuitry is there housed in five small compartments fully screened from one another by metal partitions. Holes are drilled in these partitions to take the necessary connecting wires, and some of these holes are fitted with what is known as a *feedthrough capacitor*.

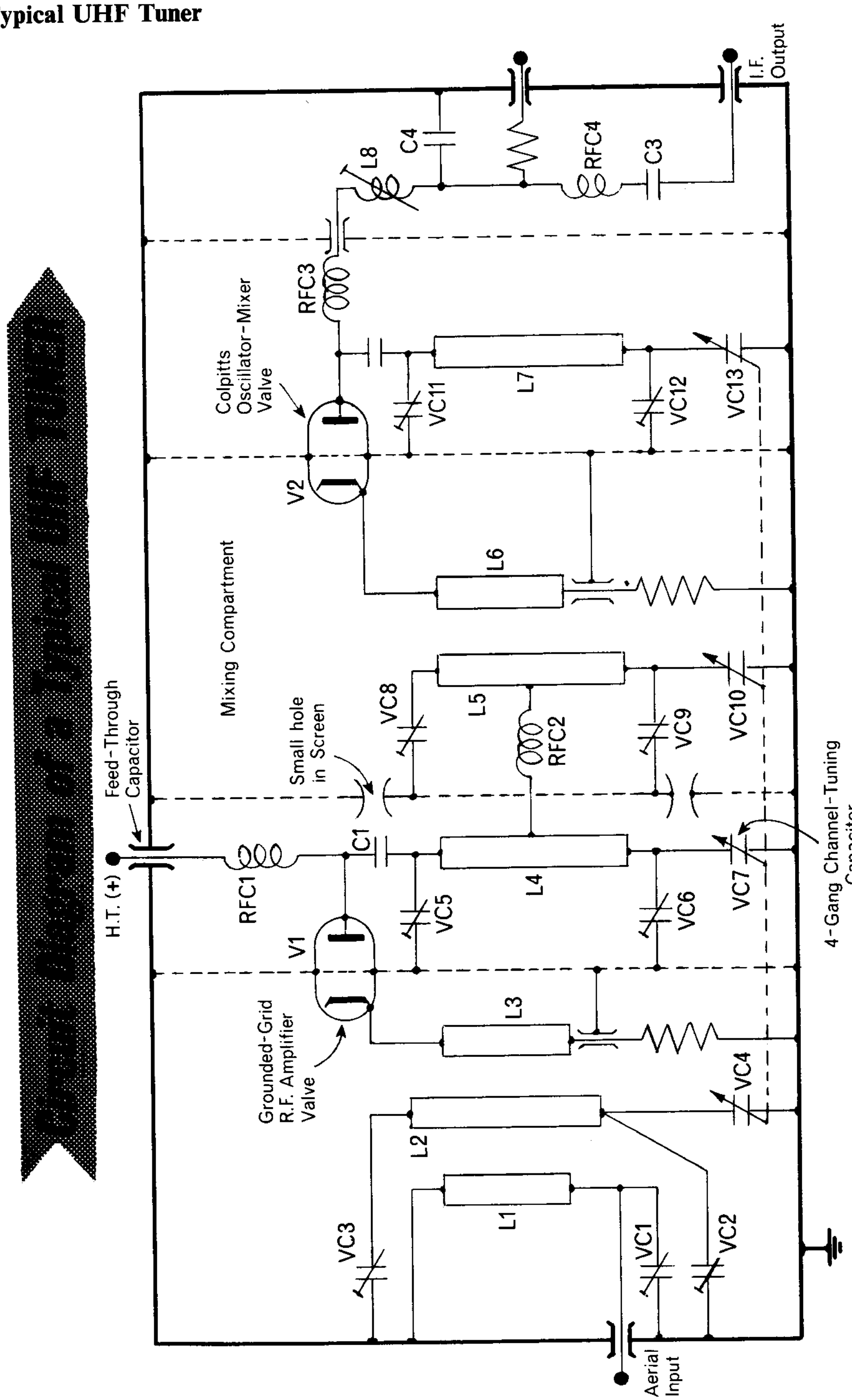
One electrode of a feedthrough capacitor is a cylindrical piece of metal soldered or bolted to the metal wall of the compartment through which it is desired to make connection. The other is the connecting wire itself as it passes through the first electrode.

The purpose of a feedthrough capacitor is to pass high-frequency a.c. signals to earth, but to allow d.c. and low-frequency a.c. signals to pass along the wire. It acts, in short, as a high-frequency decoupler.

The resonant lines themselves are all plated in silver. UHF waves find so much opposition to their passage through even good conductors that they tend to travel along the circumference of a wire rather than through its middle. (This phenomenon is known as *skin effect.*) So in order to keep the resistance of the current path as low as possible, the outside of the resonant lines are coated with a highly conductive metal.

In the UHF tuner illustrated, the first two compartments contain respectively the cathode and the anode tuned circuits of the r.f. amplifier; the third and fourth compartments contain the cathode and anode tuned circuits of the mixer; while the fifth compartment houses the tuned circuit of the i.f. output. The shaft of the four-gang variable capacitor runs through the first three internal compartment walls, and operates the variable capacitors in the first four compartments.

A Typical UHF Tuner



Radio-Frequency Amplification in the UHF Tuner

There are several special problems connected with the r.f. amplification of UHF signals received in the tuner.

In the first place, UHF signals tend to be much smaller in amplitude when they reach the aerial than do their VHF counterparts. The reason is that their higher frequency causes them to suffer much greater attenuation as they pass through the atmosphere—especially when they have to pass through fog, cloud or rain.

In the second place, although (as you know) a UHF aerial system is designed to give much higher gain than is its VHF counterpart, its necessarily smaller dimensions give it a lower signal-collection efficiency.

The result is that the UHF signal is generally much smaller than is a VHF signal when it leaves the aerial on its way into the receiver. To make matters worse, it is then apt to suffer greater attenuation during its passage through the aerial feeder cable, however good this cable may be.

What reaches the r.f. amplifier is thus a signal of very high frequency but very low amplitude. This is an awkward combination, because the high frequency makes amplification difficult, while the low amplitude makes it all the more necessary.

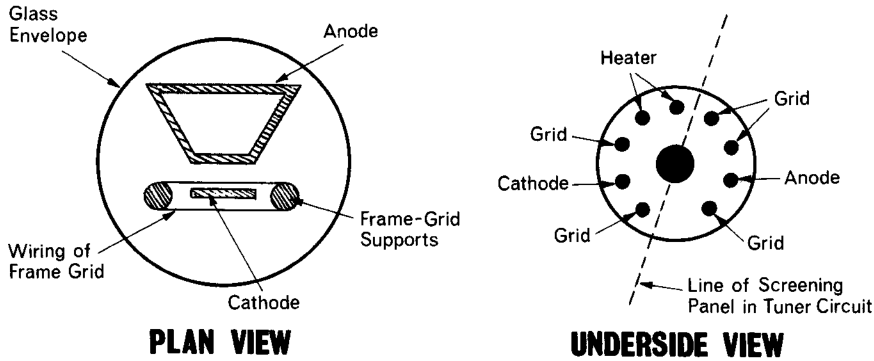
A further difficulty stems from the small size of the UHF signal, in that the signal itself is not much greater than the noise level which is inherent in any type of triode with which you are familiar. This means that little improvement in the signal-to-noise ratio can be achieved with normal triode valves, even of the frame-grid type.

The cascode amplifier, which works so well with the comparatively large VHF signal, cannot therefore be used at UHF. A pentode cannot be used either, because it cannot handle UHF frequencies; so the only solution is to use a new kind of triode specially designed to meet the triple requirements of low inter-electrode capacitance, low inherent noise, and an acceptable factor of gain.

The UHF Triode in the RF Amplifier

To meet these requirements, a new type of **UHF triode** has been developed, in which the values of interelectrode capacitance are kept small by reducing to a minimum those areas of the anode and grid, and of the anode and cathode, which actually face one another. Such a triode is illustrated below.

The UHF TRIODE



The UHF Triode in the RF Amplifier (*continued*)

You will note, in the illustration of the UHF triode opposite, that the grid of the valve is of frame-grid construction. Interelectrode capacitances are then further reduced by employing a wedge-shaped anode positioned *on one side only* of the grid, instead of completely surrounding it. Only a small area of the anode is in this way placed in close proximity to the grid and to the cathode, and the capacitances between them are so kept much smaller.

Since only one side of the cathode is "seen" by the anode, only this side needs to be coated with emissive material. The electron-collection efficiency of this arrangement is naturally not as good as that of the double-sided cathode inside a cylindrical anode; but the whole conception of the valve is based on the need for compromise. Thus, a satisfactory anode current would call for a large emissive area on the cathode, and the high mutual conductance needed between grid and cathode would demand close spacing between them. Yet such an arrangement would give rise to a C_{gk} which would be unacceptably large.

The solution must be to decide on the maximum tolerable C_{gk}, and to make do with the anode current and value of grid-cathode conductance which an emissive surface so regulated in size and position will provide.

The grid of a UHF triode is always of frame-grid construction in order to obtain a high G_m without an excessive C_{gk}.

One other construction detail of the UHF triode is of interest. When a triode is used for amplifying UHF signals, another potential source of instability is the inductance values of the connecting leads within the valve itself (*i.e.*, the leads connecting the electrodes to the base pins). These inductances can be quite high; and unless their effect is reduced, they can cause instability by resonating with the interelectrode capacitances to form tuned circuits.

In the UHF triode, therefore, the control grid is connected at five separate points to five separate pins on the valve base. The UHF triode is always connected into the r.f. amplifier circuit in the grounded-grid configuration, in order to prevent the "Miller build-up" of C_{ag} which would make it unstable. When the valve is so connected, the five pins aforesaid are connected both together and to the chassis of the set (which is effectively earth). Since the five connections are now in parallel, their effective inductance is only a fifth of that of a single lead.

The inductance values of individual leads in the UHF triode are further reduced by constructing them from thick wires plated with silver.

The degree of gain produced by a UHF triode of frame-grid construction connected in the grounded-grid configuration is a good deal lower than that produced by a cascode amplifier handling a VHF signal—typically about eight times lower. Most multi-band Dual-Standard receivers make up for this deficiency in gain by passing the i.f. output signal *through the unused mixer stage of the VHF tuner*, using the latter as a kind of pre-amplifier for the intermediate-frequency UHF signal before it reaches the main i.f. amplifier section of the receiver.

The extra amplification obtained in this way does much to ensure that the VHF and the UHF intermediate-frequency signals both reach the i.f. amplifier section at approximately equal strength.

A Complete UHF Tuner

The **r.f. amplifier** stage in the UHF tuner thus consists of a special UHF triode with its grid grounded by direct connection to the compartment wall. It is labelled V_1 in the circuit diagram on page 2.75. Its cathode and anode tuned circuits are made up of specially-shortened, capacitively-tuned resonant lines, silver-plated in order to assist the passage of the UHF waves travelling along the outer surfaces of the lines.

The signal from the aerial is taken to the coupling loop L_1, which is itself inductively coupled to a tuned circuit consisting of L_2 and the variable capacitors VC_2, VC_3 and VC_4 connected across its ends. This tuned circuit of L_2 is in turn coupled to the cathode of V_1 through another coupling loop L_3. This method of coupling is chosen in order to reduce the damping effect on the input signal of the low input impedance of the valve.

The circuit of L_2 is initially tuned by the makers with the aid of the trimming capacitors VC_2 and VC_3 and of one section (VC_4) of the four-gang channel-tuning capacitor.

The amplified signal at the anode of V_1 is coupled through C_1 to the tuned circuit formed by L_4, VC_5, VC_6 and VC_7. This tuned circuit forms the primary of a band-pass transformer, the secondary of which (L_5) is an identical tuned circuit in the next compartment. Capacitive coupling between the two tuned circuits of this transformer is effected through two small holes in the compartment screen; and the circuits are further connected at their centre points through the small inductor RFC_2.

The degree of coupling between the tuned circuits of L_4 and L_5 is arranged to produce a double-humped "over-coupled" response curve. You will see at the end of this Section that a response curve of this shape is needed to pass both the sound and vision signals to the mixer stage.

The half-dozen feedthrough capacitors which you will see in the illustration on page 2.75 pass d.c. but take high-frequency a.c. to earth through the metal walls of the tuner and the chassis of the receiver. An example is the feedthrough capacitor which supplies HT to the anode of V_1. (The purpose of the choke RFC_1 in this circuit is to prevent undesirable coupling between stages in the tuner from taking place through the HT supply.)

You cannot use in the UHF tuner the kind of *frequency-changer* circuit, consisting of a triode oscillator and a pentode mixer, which does duty in the VHF tuner. The reason is that the high degree of noise generated in such a circuit (mainly in the pentode) would swamp the signal.

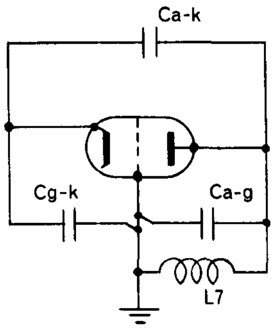
Used instead is a single triode valve connected to form what is called a *self-oscillating mixer circuit.* Such a circuit not only provides the required local-oscillator signal, but also mixes it with the wanted signals fed in from the r.f. amplifier. The output is, of course, two i.f. signals of much lower frequency, one carrying the amplitude and the other the frequency modulations of the wanted vision and sound signals, respectively.

Like its VHF counterpart, the local-oscillator in the UHF tuner is made to oscillate at a frequency *above* that of the channel signal. This means that it must operate at the very high frequency of 900 MHz. At this level, frequency stability is not easily maintained. Some UHF tuners, notably those offering the push-button type of channel selection, solve the problem by incorporating an automatic frequency-control circuit which corrects the oscillator for frequency drift by deriving a control voltage from a frequency discriminator circuit driven from the vision i.f. amplifier, and by using this

A Complete UHF Tuner (*continued*)

voltage to vary the potential across a semi-conductor diode of variable capacitance connected across the tuned circuit of the oscillator.

The self-oscillating mixer circuit mentioned on the last page (and designated V_2 in the large diagram on page 2.75) is most easily understood if it be reduced to its "equivalent" form. This is done in the illustration below.



Equivalent Circuit of the UHF OSCILLATOR

The oscillator valve V_2 is connected as a grounded-grid Colpitts type (*Basic Electronics*, page 3.63), and relies on its own inter-electrode capacitances to provide the feedback necessary for oscillation. Thus, in the diagram above, the feedback between the anode and cathode circuits is provided by the anode-to-cathode and the grid-to-cathode capacitances—C_{ak} and C_{gk} respectively—while the anode-to-grid capacitance —C_{ag}—forms part of the anode tuned circuit.

L_7 is a capacitively-tuned resonant line whose resonant frequency determines the operating frequency of the oscillator. The tuning of L_7 is carried out by variation of the VC_{13} section of the four-gang channel-tuning capacitor (and also, of course, by the two trimming capacitors VC_{11} and VC_{12}, preset by the manufacturers).

Mixing of the channel and local-oscillator signals takes place in the third, or middle, screened compartment of the tuner. This compartment contains essentially the cathode circuit of V_2 and the second part (L_5) of the tuned-transformer circuit which you saw was capacitively coupled to L_4 in the anode circuit of the r.f. amplifier. The signal is injected into the oscillator circuit by mutual inductance between L_5 and the small coupling loop L_6 in the cathode circuit of V_2.

In the **output circuit** of the UHF tuner, the i.f. signal produced in the mixer stage from the beating together of the channel signal and the signal from the LO is taken through a choke RFC_3 (whose purpose is to offer a high impedance to the oscillator signal and so keep it out of the HT supply and intermediate-frequency circuits) to a tuned coil, L_8, in the anode circuit of V_2. This tuned coil is situated in the fifth and last of the five screened compartments into which the UHF tuner is divided.

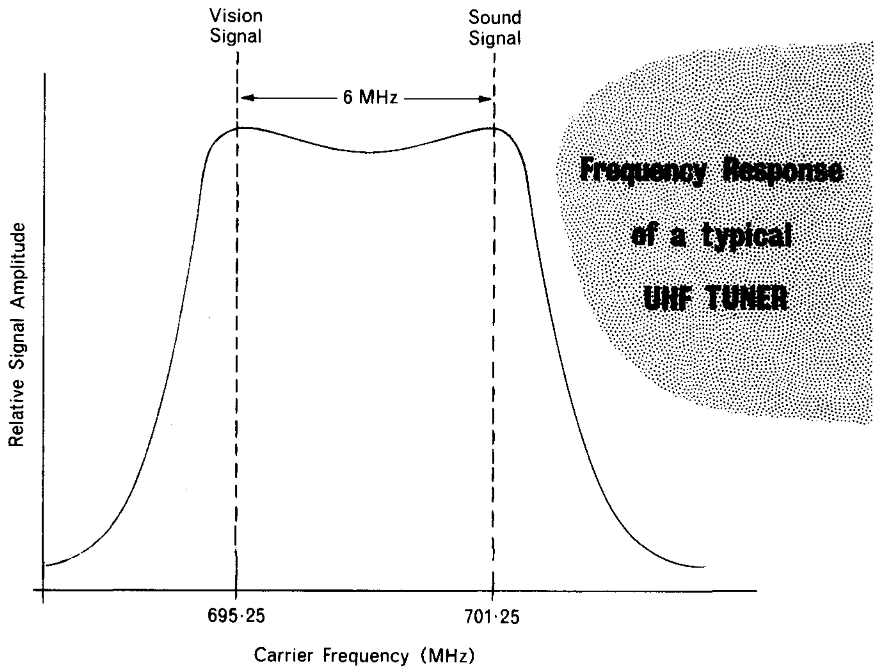
It forms one-half of a tuned transformer circuit of which you will be meeting the second half in the **IF Amplifier.** The two halves of this transformer circuit, which are physically some distance apart, are coupled by a method known as *bottom capacitance coupling*, in which the capacitance of the coupling cable itself is made to provide a significant fraction of the total coupling capacitance.

A Complete UHF Tuner (*continued*)

The i.f. signal is taken to the output terminal of the tuner through another choke, RFC_4. In combination with the two small capacitors C_3 and C_4, this choke forms a filter which passes the low-frequency i.f. signal but filters off to earth any of the much-higher-frequency signals from the local oscillator which may find their way into the output circuit.

Frequency Response in the TV Tuner

Ideally, the overall frequency response of any TV tuner, VHF or UHF, would be completely flat over the full range of frequencies occupied by the sound and vision carriers of any given channel signal, and zero at all frequencies outside those limits. In practice, an adequate approximation to this ideal is attained by so arranging the coupling of the various tuned circuits in the tuner that a response of the shape illustrated below is obtained.



You will see that the pattern has a broad top with two humps on it—one corresponding to the frequency (or the i.f.) of the vision carrier, and the other corresponding to the frequency (or i.f.) of the sound carrier.

The illustration shows the frequency response of a typical UHF tuner, but that of a VHF counterpart would not be very different.

The overall frequency width of such a response curve as that shown is sufficient to embrace most of the frequencies contained in any wanted signal.

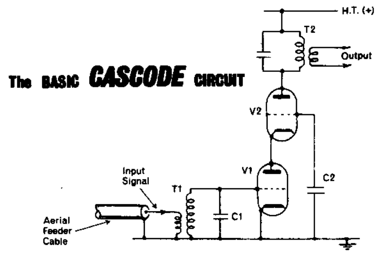
REVIEW of the TV Tuner

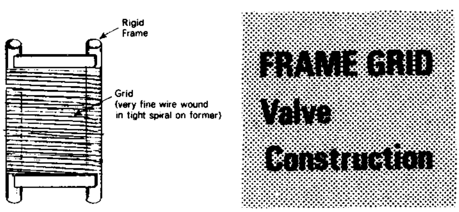
The tuner is the first stage in the TV receiver. Its function is to select the required channel signal from those fed to it by the aerial, to amplify this signal to a usable level, and to convert its sound and vision frequencies into the sound and vision intermediate frequencies of the receiver.

Different types of tuner are needed for handling signals in the VHF Bands 1, 2 and 3 (Channels 1–13), and for signals in the UHF Bands 4 and 5 (Channels 21–68). Dual-Standard receivers used in Britain to operate on both 405 and 625 lines are fitted with both types of tuner. Complex switching arrangements are involved when the viewer wishes to change over from one system to the other.

The three main sections of a TV tuner cover the *r.f. amplification* of the wanted sound and vision signals, their *conversion to a usable intermediate frequency*, and *selection of the desired signal channel.* At VHF, all the operations required can be performed by making use of the properties of the *LC* tuned circuit, but at ultra-high frequencies this type of circuit will not work. The UHF tuner has therefore to make use instead of the properties of the quarter-wave resonant line.

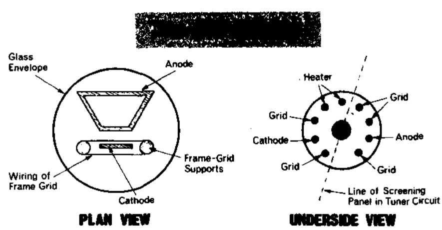
Radio-frequency amplification—In the VHF tuner, the r.f. amplifier consists of a double-triode valve connected in a *cascode* circuit. This type of circuit combines the stability of the grounded-grid configuration with the good gain of the grounded-cathode configuration, and minimizes their respective disadvantages.





Frame-grid construction gives a valve the advantages of close spacing between grid and cathode while minimizing C_{gk}. The grid is constructed of very fine wire wound in a tight spiral round a rigid frame. The small air gap between adjacent wires greatly reduces C_{gk} even when the cathode is positioned very close to them.

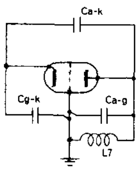
R.F. amplification at UHF has to be achieved differently, for the much smaller UHF signal would be drowned by the inherent noise level of the cascode. A single UHF triode is used instead. The narrower end of a wedge-shaped anode is positioned on one side only of a frame-type grid, so as to keep interelectrode capacitances as low as possible.



The low gain of such a valve is often compensated by passing its output signal through the unused mixer stage of the VHF tuner.

REVIEW of the TV Tuner (*continued*)

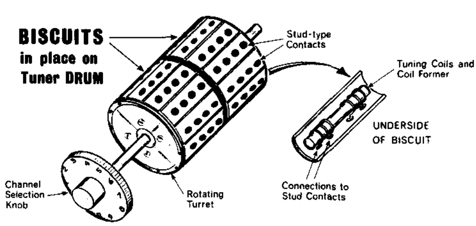
Frequency changing in the VHF tuner is usually done by means of *separate local-oscillator and mixer* circuits combined in a single triode-pentode envelope. The triode functions as the local oscillator, the pentode as the mixer. The channel signal from the cascode amplifier and the signal produced by the local oscillator are both fed to the control grid of the pentode, where mixing of the additive type takes place.



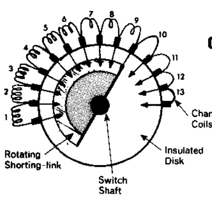
Equivalent Circuit of the UHF OSCILLATOR

The very small UHF signal would be drowned by the noise inherent in such a multiple-valve arrangement, and its frequency has to be lowered by other means. A single triode circuit is used instead, and is made to perform the dual function of local oscillator and mixer by being connected as a self-oscillating mixer. Such a circuit has poor gain; so the still-very-small UHF intermediate-frequency signal is often passed for pre-amplification through the idle mixer stage of the VHF tuner.

Channel selection is achieved in the VHF tuner when the viewer operates a control which connects physically-different inductor coils into the r.f. amplifier and frequency-changer circuits. On the *turret tuner* the 13 different sets of coils needed to tune into the 13 channels in Bands 1, 2 and 3 are mounted on insulated biscuits to form a hollow drum. Wiper contacts connect the selected set of coils into the appropriate circuits in the tuner.



An alternative is to use the *incremental tuner*, in which a rotary switch is moved to short out parts of a larger total inductance. A number of coils, wired together in series, are mounted round the periphery of flat disks called wafers or banks. They are then progressively shorted out when the operating shaft of the switch (to which they are mechanically linked) is rotated by the viewer.



One Bank of a VHF INCREMENTAL TUNING SWITCH

When Set is switched to Channel 10
— Coils 1–9 are shorted-out
— Coils 10–13 are in-circuit

In the UHF tuner of the multi-channel type, channel selection is accomplished by means of a four-gang variable capacitor mounted on a shaft which runs through three of the compartment walls inside the metal box housing the tuner. When the viewer rotates this shaft by operating the channel-selection control knob, tuned circuits in four of the five compartments of the tuner are re-tuned to a different frequency. Continuous tuning over the full range of 44 channels used for TV in Bands 4 and 5 is thus made possible.

UHF tuners of the *push-button type* are tuned to four channels only, in Bands 4 and 5. The receivers to which they are fitted would need adjustment before they could pick up signals from a station in another part of the country transmitting in different channels.

§12: THE IF AMPLIFIER

When the sound and vision signals, still unseparated, leave the tuner, their amplitudes are very low—only of the order of a millivolt or so. This is not sufficient to operate the next main stages in the receiver, which require signal amplitudes ranging from 1 to 5 volts.

It is the principal job of the **intermediate frequency amplifier** to apply to the signals amplification of that order of magnitude—say, an overall gain in the region of 12,000 times.

There is no particular problem involved in achieving this degree of gain. The signals leaving the tuner have all, as you know, been reduced to a comparatively low intermediate frequency. (**In the VHF system working on 405 lines,** the i.f.'s are 34·65 MHz for the vision signal and 38·15 MHz for the (AM) sound signal. **In the UHF system working on 625 lines,** they are 39·5 MHz for the vision signal and 33·5 MHz for the (FM) sound signal.) All these frequencies are low enough to be handled, without much danger of distortion or of excessive noise, by the kind of amplifying devices you learnt about in Parts 2 and 6 of *Basic Electronics.*

Special problems arise, however, in the rejection of interference signals, and in the shaping of the frequency response curves to accommodate the single-sideband transmission of both the VHF and the UHF signals. There are also difficulties because of the different ways in which the VHF and the UHF sound signals are handled in the British Dual Standard receiver. To recapitulate:

In the 405-line system, the sound and vision signals from the desired channel are separated as soon as they enter the i.f. amplifier stage, and are then passed to *two different i.f. amplifier circuits.* The sound signal then goes off to the sound detector and the vision signal to the video detector. (This is called the **split-sound** method of processing the sound signal.)

In the 625-line system, the sound and vision signals are amplified *together* in a single i.f. amplifier circuit and are not separated until they reach the video detector. (This is called the **intercarrier** method of processing the two signals.)

The i.f. amplifier stage of the Dual-Standard receiver thus requires two separate i.f. amplifier circuits for handling the VHF signal. For reasons of economy, the circuit which handles the VHF *vision* signal is also used to amplify the UHF signal, in which the sound and vision signals are still both present.

Because of the presence of the UHF sound signal, this latter circuit cannot accurately be called the *Vision IF Amplifier*, though that is the principal job it has to do. So let us christen it **IF Amplifier A**—though you should remember that the name is an unofficial one. The functions of this IF Amplifier A are:

The i.f. amplification of the VHF vision signal;

The i.f. amplification of the UHF sound and vision signals.

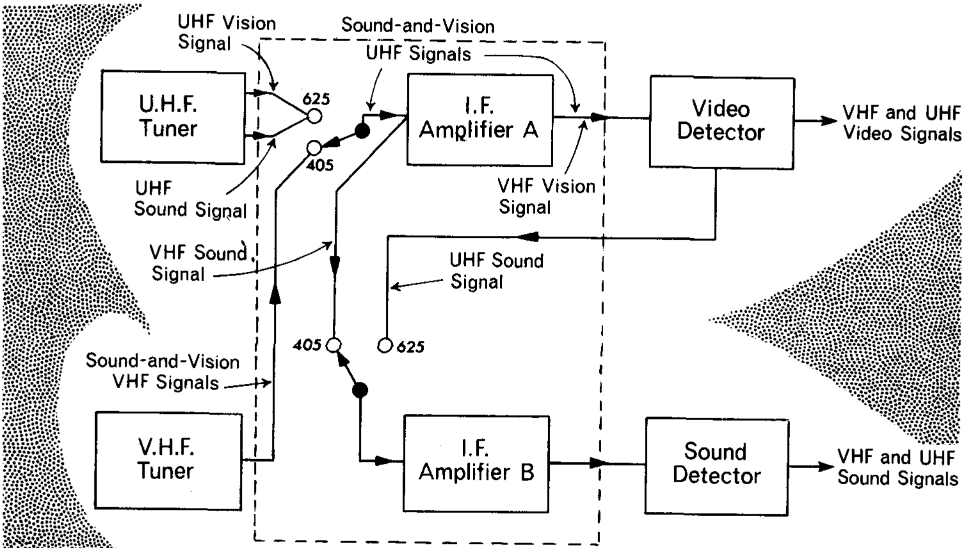
The second amplifier—let us call it (equally unofficially) **IF Amplifier B**—is a sound amplifier only. Its functions are:

The i.f. amplification of the amplitude-modulated VHF sound signal;

The i.f. amplification of the frequency-modulated UHF sound signal passed back to it from the later stage (the Video Detector) in which the UHF sound and vision signals are finally separated.

The IF Amplifier Stage

The rather complicated arrangement outlined on the last page will be easier to understand if you study the block diagram below. The dotted rectangle in it outlines the IF Amplifier block considered in this Section.



Block Diagram of the I.F. AMPLIFICATION STAGE in the British Dual-Standard Receiver

Separating the VHF Sound and Vision Signals

The first thing is to see how the VHF sound signal (on 38·15 MHz) is separated from the VHF vision signal (3·5 MHz away on 34·65 MHz) before the latter reaches IF Amplifier A. Bear in mind that, as you will see later on, the frequency bandwidth of the sound signal is the comparatively narrow one of about 600 kHz, but that of the vision signal is very much wider.

Separation of the two signals is accomplished by using in different ways members of a family of circuits which are generally called *rejector circuits* in Britain, and *traps* in the United States. Since you will be meeting quite a few of these circuits in the Dual-Standard receiver, it is worth taking a page or two at this point to see how they work.

Traps are no more than *LCR* resonant tuned circuits, either series- or parallel-connected, consisting of inductors and capacitors plus a resistive element which can either be a physical resistor connected into the circuit or else the inherent resistance of the circuit components themselves. The four basic types are illustrated and explained on pages 2.86 and 2.87.

Turn to those pages now to get the general principles into your mind. You will see that the important difference between the circuits lies in what they do to a signal whose frequency lies close to the resonant frequency of the trap. Circuits of **Types A and B** tend to *pass* signals of the resonant frequency while blocking or shunting signals of all other frequencies; while circuits of **Types C and D** do the opposite, *blocking or shunting* signals of the resonant frequency while passing signals of other frequencies.

Separating the VHF Sound and Vision Signals (*continued*)

Bear the following points carefully in mind when you are thinking about the rejector circuits illustrated on the next two pages:

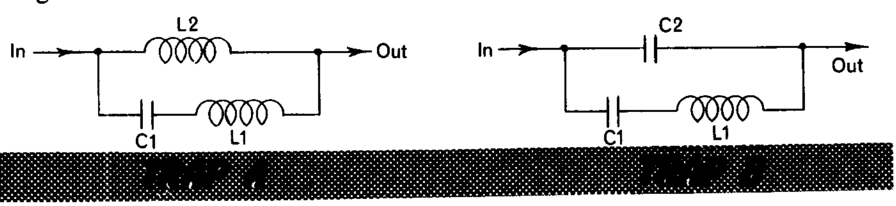
(*a*) That when $X_L = X_C$ in a **series** circuit, impedance to current flow is minimum. When $X_L = X_C$ in a **parallel** circuit, impedance is maximum (*Basic Electricity*, Part 4).

(*b*) That effective shunting only takes place when the parallel connection offers to the signal an impedance path *which is low relative to the input impedance of the load across the output*. This load is, of course, the next stage in the receiver.

(*c*) That the terms "blocking" and "shunting" used in connection with rejector circuits are only relative. Although in all the illustrations on pages 2.86 and 2.87 an open switch has (for greater emphasis) been drawn to represent a very high reactance, and a closed switch to represent a very low one, it would have been more correct in both cases to draw in a *resistance* marked as being of high or low value respectively. Some current will always leak through even a very high Z; and neither inductive nor capacitive reactances are ever infinitely high. The "open circuits" shown should therefore be regarded as very high impedances severely attenuating the flow of current; while the "closed switches" represent paths of low relative impedance which most of a given current will take in preference to a path offering a higher impedance.

The drawback to the basic types of trap shown on pages 2.86 and 2.87 is that they are not very selective. Their impedances alter only slowly as signal frequencies move away, in either direction, from the resonant frequency of the trap; and their frequency response curves tend to be rather low and flat. Such simple circuits are therefore not suitable for discriminating between signals whose frequencies lie comparatively close together; for the wanted signal may be severely attenuated (or, in parallel-resonant circuits, largely shunted) by meeting an impedance of inappropriate value.

It is possible to design traps having much better selectivity and much sharper attenuation characteristics (that is to say, with a high and "peaky" response curve). Two such traps are shown below. The one on the left (**A**) is designed to block a particular unwanted signal whose known frequency is *higher* than that of the wanted signal; the one on the right (**B**) to block a signal whose known frequency lies *below* that of the wanted signal.

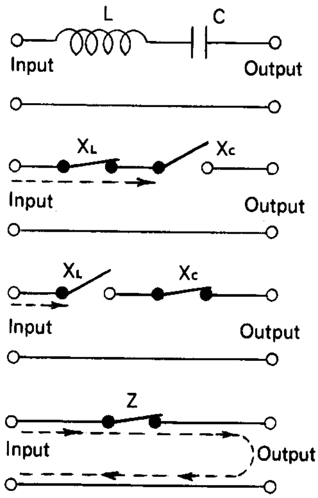


Trap A works as follows. The value of L_2 has been so chosen that, to signals of frequencies lower than the f_r of the trap, its reactance offers little opposition. The signals therefore pass through the trap without attenuation. To the wanted signal itself, C_1 and L_1 offer a predominantly capacitive alternative path, which still presents a high reactance. At a given frequency lying **above** that of the wanted signal, however, it is arranged that the net capacitive reactance of the C_1–L_1 combination shall balance the inductive reactance of L_2. The whole trap becomes a parallel-resonant circuit whose impedance at resonance is very high, and the unwanted signal is blocked.

The working of **Trap B** is explained on page 2.88.

REJECTOR CIRCUITS

A



Series Connected: Series Resonant

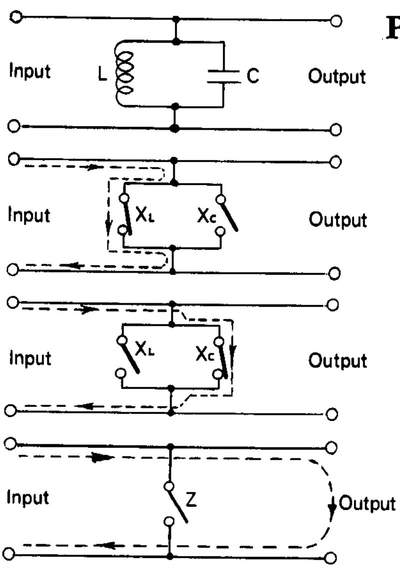
The Basic Circuit

When Signal Frequency is **Below Resonance,** X_L is low, but X_C is high enough to **Block the Signal.**

When Signal Frequency is **Above Resonance,** X_C is low, but X_L high enough to **Block the Signal.**

When Signal Frequency is **At Resonance,** $X_C = X_L$, and through the resulting low Z **Maximum Signal Passes.**

B



Parallel Connected: Parallel Resonant

The Basic Circuit

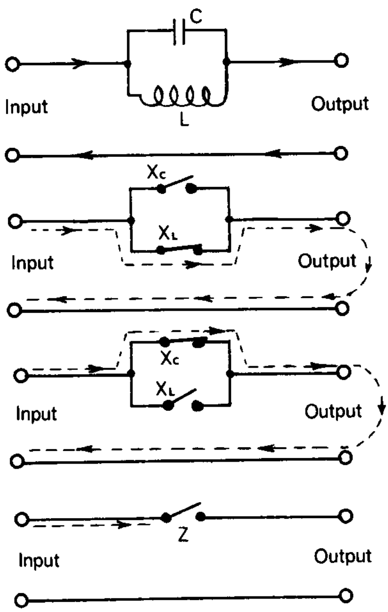
When Signal Frequency is **Below Resonance,** X_L is low and provides a path of relatively low Z, so **Shunting the Signal.**

When Signal Frequency is **Above Resonance,** X_C is low and provides a path of relatively low Z, again **Shunting the Signal.**

When Signal Frequency is **At Resonance,** $X_C = X_L$. The Parallel Combination offers a high Z. Little of the Signal is shunted, and **Maximum Signal passes.**

— OR TRAPS

C



Series Connected: Parallel Resonant

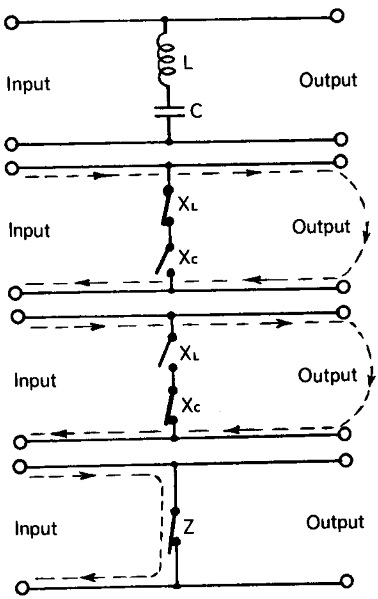
The Basic Circuit

When Signal Frequency is **Below Resonance,** X_L is low enough to pass **Maximum Signal to Output**.

When Signal Frequency is **Above Resonance,** X_C is low enough to pass **Maximum Signal to Output**.

When Signal Frequency is **At Resonance,** $X_C = X_L$. The Parallel Combination offers a high Z, which **Blocks the Signal**.

D



Parallel Connected: Series Resonant

The Basic Circuit

When Signal Frequency is **Below Resonance,** X_C is high and **Maximum Signal Flows to Output**.

When Signal Frequency is **Above Resonance,** X_L is high and **Maximum Signal Flows to Output**.

When Signal Frequency is **At Resonance,** $X_C = X_L$, and the resulting low Z **Shunts the Signal**.

Separating the VHF Sound and Vision Signals *(continued)*

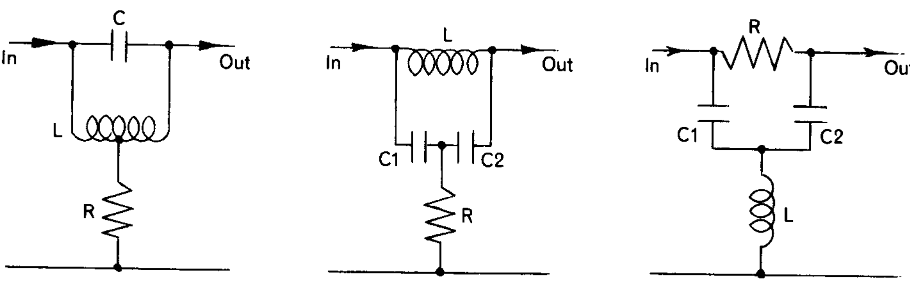
Trap B in the illustration near the foot of page 2.85 works as follows. To frequencies above that of the wanted signal C_2 offers very low impedance, while the C_1–L_1 combination offers a very high (and predominantly inductive) reactance. C_1, L_1 and C_2 are so chosen, however, that at a given frequency **below** that of the wanted signal, the net inductive reactance of C_1–L_1 becomes exactly equal and opposite to the capacitive reactance of C_2. The trap becomes a parallel-resonant circuit at the frequency of the unwanted signal, and so gives it maximum attenuation.

Series-resonant equivalents of the two traps described also exist, but you now know enough of the general way in which rejector circuits work to find little difficulty in understanding how one of them works when you meet it.

All these traps are simple and cheap to manufacture, and they serve many purposes in the receiver adequately well. But it is often necessary to achieve much larger attenuation of an unwanted signal—and of an unwanted signal, moreover, whose frequency lies inconveniently close to that of a signal which you want to pass. More efficient traps having these capabilities are known as **bridged-T rejector circuits.**

Bridged-T rejector circuits come in a good many variations, but the three shown below are among the most widely used. All, you will see, consist of a simple arrangement of inductors, capacitors and resistors, with one component always forming a "bridge" across the main circuit in the manner you briefly studied on pages 2.85–2.87 of *Basic Electricity.*

BRIDGED-T REJECTOR CIRCUITS



Each of the above traps offers maximum attenuation of the signal at a single frequency—which is the resonant frequency of the LC combination. The value of the resistor in each circuit is carefully chosen to ensure that the trap becomes "balanced" at this frequency, for in such a state of balance a bridge circuit has almost zero output.

The resistors used in bridge circuits in a TV receiver are usually of fixed value; but in other applications where low cost is less important a variable resistor is often used instead, so that precise balance can be achieved over a given range of frequencies.

Bridged rejector circuits provide very sharply-tuned frequency response curves, and possess an unusually high effective impedance at resonance. They are therefore useful for removing (or very severely attenuating) an unwanted signal whose frequency lies close to that of the wanted signal; and they can even be used for "cutting out" a narrow unwanted slice from a frequency response curve altogether.

Separating the VHF Sound and Vision Signals (*continued*)

Now that you know in principle how rejector circuits work, you will soon grasp how the VHF sound and vision signals are separated from one another at the input of IF Amplifier A in the Dual-Standard receiver.

Remember that no electronic circuit can differentiate between wanted and unwanted signals fed to it, unless it has been designed to do so. It will react according to its nature, irrespective of whether its input is hopefully labelled "sound signal", "vision signal" or anything else. Thus if a portion of the sound signal reaches the picture tube of a TV set, the latter will react just as if this signal were part of the wanted vision signal. A condition known as *sound-on-vision* will arise; and the picture appearing on the screen will be distorted.

In practice, sound-on-vision is so serious a danger that a high-grade rejector circuit is used to combat it. A bridged-T rejector *resonant to the frequency of the sound signal* is therefore connected in series with the circuit leading to the main part of IF Amplifier A (it is labelled F3 in the full circuit diagram on page 2.99), and the sound signal is effectively blocked by it from reaching that section.

The converse effect of *vision-on-sound* is accepted as having a less damaging practical effect; and a simple parallel-resonant trap connected across the line taking the VHF signal to IF Amplifier B is generally considered sufficient. This trap also (F1 in the diagram on page 2.99) is made to *resonate at the frequency of the sound signal.* With its moderately good Q, it passes the 600 kHz bandwidth of the sound signal itself quite satisfactorily, but shunts all signals whose frequencies lie outside this band (including most of the VHF vision signal) to earth.

The Requirements of IF Amplifier A

You are now left with the principal section of IF Amplifier A having two inputs—the VHF vision signal and the UHF sound and vision signals. What requirements must it fulfil in amplifying these signals acceptably?

It must do two things.

❶ **It must deal now, at a moment when they are still quite weak, with certain interference signals which would be much harder to eliminate at a later stage when they had been amplified to greater strength.**

❷ **It must apply a reasonably even degree of effective amplification over the operational bandwidth of a signal which has had one of its sidebands partially suppressed.**

Let's deal with the interference problems first. You saw in Part 5 of *Basic Electronics* (pages 5.48 and 5.56) how *image-frequency* (or *second-channel*) interference can be caused by the intrusion of unwanted signals on a frequency *twice the value of the i.f. above or below* the frequency of the wanted signal. (This is true of any type of receiver working on the superhet principle, whether it be used for sound radio, for TV or for anything else.) You also saw that it was possible to reduce the possibility of image-frequency interference by arranging for a high intermediate frequency to be produced in the mixer stage; but that this could only be done at the cost of reducing the selectivity of the receiver.

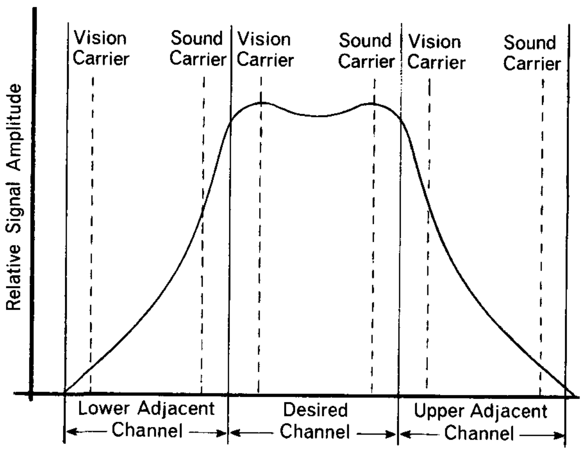
In the British Dual-Standard receiver, the i.f.'s used are high enough to cut out most second-channel interference; but they are so high that the opposite danger of **adjacent-channel interference** becomes a real problem calling for special measures at the i.f. amplifier stage.

IF Amplifier A—The Requirements (*continued*)

Adjacent-channel interference is introduced into the signal by unwanted signals whose frequencies lie close to its own. An example would be a TV receiver operating in Channel 3 but suffering interference from Channels 2 and 4. The very strong sound carrier signals radiated by the BBC in Channel 1 are also apt to intrude on signals several MHz away from them in frequency.

These interference signals mix with the output of the local oscillator in the tuner, and produce additional, unwanted, sound and vision i.f.'s which pass into the IF Amplifier stage *above and below the i.f.'s of the signals in the desired channel.*

The illustration below shows the frequency response of a typical TV tuner. You will see that the curve is broad enough, and tapers away slowly enough, for unwanted i.f.'s to be present in appreciable strength at the input to the IF Amplifier. The sharpening of the frequency response effected by the i.f. tuned circuit in the output of the mixer stage has not been enough; and it is an essential part of the job of the IF Amplifier to improve the shape of the curve (and so to sharpen the Q of the receiver) to its final form.



FREQUENCY SPECTRUM of the Input Signal to the I.F. Amplifier Stage (625-line System)

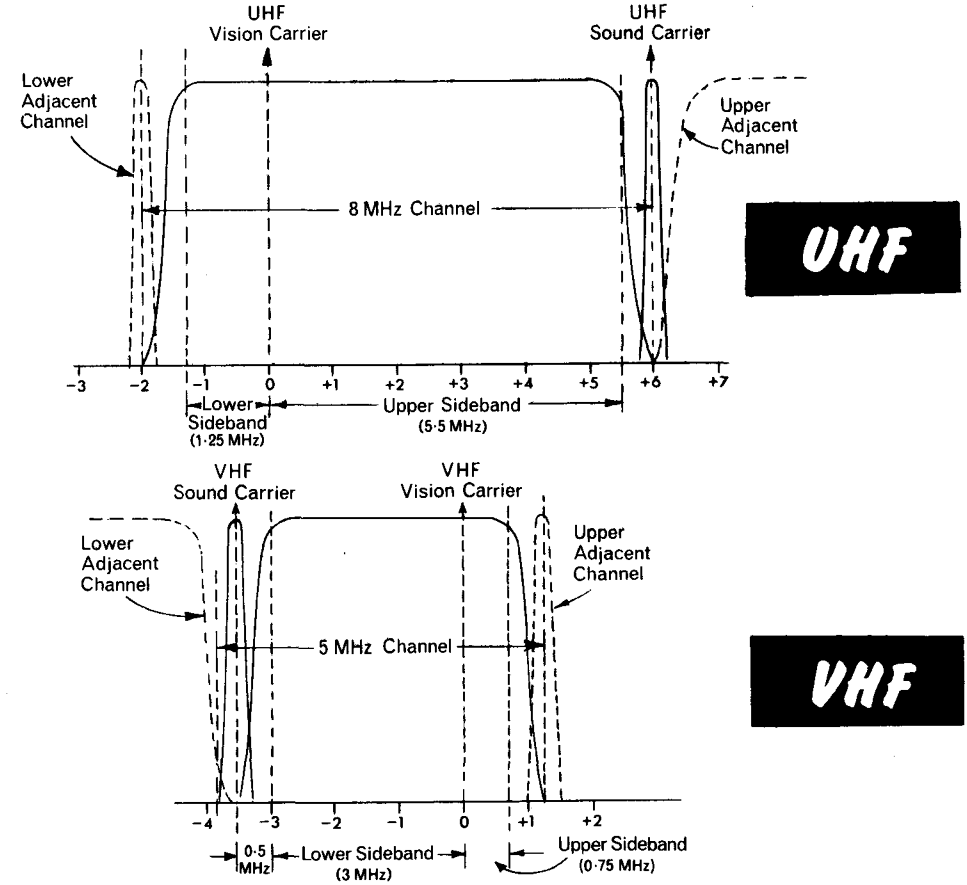
Think of the frequency spectrum above as the "raw material" with which the IF Amplifier stage is presented when the receiver is switched to the 625-line system. (A similar curve, though with some differences, is presented to the IF Amplifier when the set is switched to 405 lines.) What you want to extract from these two curves are the two frequency spectra shown in the double diagram on the opposite page: they are, respectively, the "true" spectra of the sound and vision i.f. signals in the VHF system and the "true" spectra of the same signals in the UHF system.

Note how both curves show maximum signal intensity throughout those sidebands which are transmitted in full, but maximum signal intensity *only on those parts of the other sideband which are not suppressed.* Note, too, how sharply the curves fall away beyond these limits.

Note also (shown in dotted line) the positions in the frequency spectrum which the nearest of the unwanted i.f.'s—the upper and lower adjacent channels—would in each case occupy if they were present; and also the position in each spectrum of the respective sound carriers. (The bandwidths of both sound carriers have, of course, been greatly exaggerated in relation to the widths of their corresponding vision signals, in order to show them at all.)

IF Amplifier A—The Requirements (*continued*)

In both the diagrams below, frequencies below and above the vision carrier have been marked with (−) and (+) values respectively. Remember that these scales do not aim to show the actual magnitude of either signal, but only its value *relative to the frequency of its vision carrier.*



The True Frequency Spectra of the Received VHF and UHF Signals

Imagine that you are the designer of the IFA stage of a receiver which has to handle two signals having the frequency spectra shown in the double illustration above. What frequency response are you going to build into the IFA to ensure that it will provide the correct distribution of signal power, after i.f. amplification, over the entire spectrum of both signals?

The problem centres, of course, round those partially suppressed sidebands. You will recall from Part 1 that, in the British 625-line system, the *upper* sideband of the vision carrier is transmitted in full up to 5·5 MHz, whereas the lower (vestigial) sideband is transmitted in full only up to 1·25 MHz and is suppressed thereafter. In the 405-line system, the *lower* sideband is transmitted in full up to 3 MHz, while the upper (vestigial) sideband is suppressed after 0·75 MHz.

What is the real difficulty which these partially suppressed sidebands present?

IF Amplifier A—Signal Power Distribution

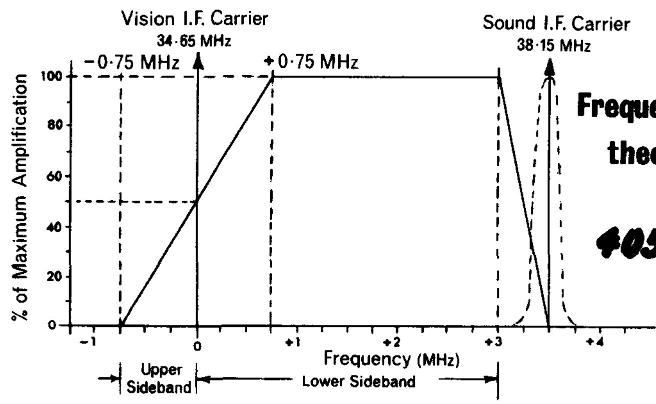
You learnt in *Basic Electronics* that it is the sidebands of any AM wave which carry the signal information, and which contain the signal power. You also know, from Part 1 of this Series, that it is the higher frequencies, *those furthest away from the vision carrier*, which are needed to reproduce on the screen the sharp variations between black and white which constitute the fine detail ("highlights") of the picture. The lower frequencies, *those nearer the carrier*, reproduce only the varying shades of grey which go to make up picture background. (Recall the much wider bandwidth required to reproduce the finish of the 100 metres at the Olympic Games than that needed to represent the angling competition on the pier at Southend.)

You also know that, with the aim of limiting overall bandwidth, most of one of the sidebands of a TV transmission is suppressed. Part of the process of doing so is to give zero amplification to the frequencies carrying the unwanted bits of the sideband.

But with a partially suppressed sideband a difficulty arises at the receiver over picture signal distribution. The remaining part ("vestige") of a partially suppressed sideband is the "grey-reproducing" section of it which lies nearest to the carrier. So if you apply 100% amplification to the full range of frequencies received, you will have two frequency ranges (one above and one below the carrier) transmitting "grey" background, to only one range of frequencies transmitting picture highlights. The resulting over-emphasis on background at the expense of action will look very unnatural on the screen.

The solution adopted is to arrange for IF Amplifier A to give varying degrees of amplification to the band of frequencies lying closest to the vision i.f. carrier on its either side. Minimum amplification is applied to the received signal at the limit of the partially suppressed sideband, and the degree of amplification applied then rises linearly until it reaches 100% at the equivalent point on the other sideband (which is, of course, being transmitted in full). The vision i.f. carrier itself lies (theoretically) half-way up this slope, at the point at which 50% of the maximum amplification is applied to the signal.

This solution will be easier to understand if you look at the diagram below. It shows the theoretically-desirable frequency response curve of the **405-line** vision i.f. amplifier when allowance is made for the partial suppression of the upper sideband of the signal. (It is one of the difficulties of explaining this business that the polarities of both sidebands have at this stage been reversed by the local oscillator in the tuner, so that the sideband whose values are marked with (+) values in the diagram is in fact the *lower* sideband, and *vice versa.*)



The Frequency Response Curve theoretically desirable for the *405-LINE VISION I.F. SIGNAL*

IF Amplifier A—Signal Power Distribution (*continued*)

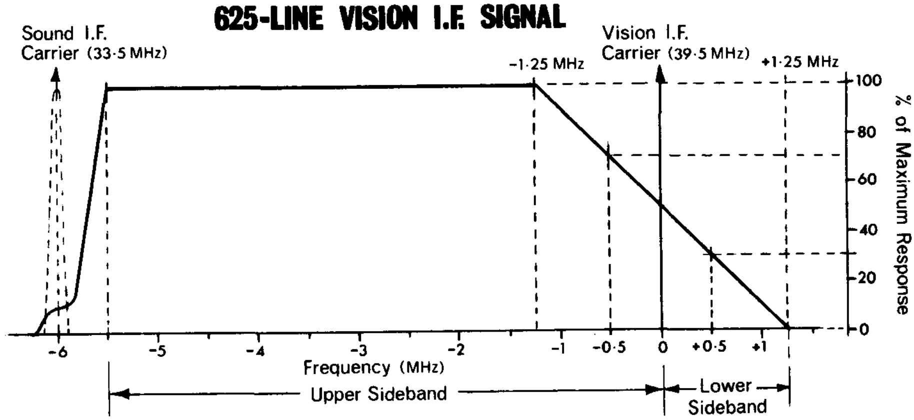
You will see from the diagram on the last page that no problem arises with signal frequencies more than 0·75 MHz away from the carrier. Full amplification is applied to all frequencies between (+) 0·75 MHz and (+) 3 MHz, and zero amplification to all frequencies below (−) 0·75 MHz.

Within the range (−) 0·75 MHz to (+) 0·75 MHz, however, the degree of amplification applied varies. As soon as frequencies in the partially-suppressed upper sideband start receiving a degree of amplification, so it becomes necessary to reduce from 100% the degree of amplification applied to the corresponding frequencies on the other side of the i.f. carrier. Thus a signal whose frequency is, say, 0·50 MHz above that of the i.f. carrier will receive about 80% of full amplification, while the corresponding signal whose frequency is 0·50 MHz below the carrier will receive only about 20%.

At all other points on the slope, signals whose frequencies lie similarly equidistant, (+) and (−), from the i.f. carriers likewise receive degrees of amplification which add up to 100% of maximum. In other words, the *gross amplification* applied over the (−) 0·75 to (+) 0·75 MHz range of the two sidebands is always 100%, and the initial power distribution of the transmitted signal is accurately preserved.

Exactly the same considerations apply to the basic frequency response curve desired of IF Amplifier A when the receiver is operating on the **625-line** system. In the diagram below, the linear slope in the response curve starts dropping at (−) 1·25 MHz, and the percentage of full amplification applied to the signal falls to zero at (+) 1·25 MHz. At all points on the slope, the *gross amplification* applied to "corresponding" frequencies above and below the carrier adds up to 100%.

The Frequency Response Curve theoretically desirable for the 625-LINE VISION I.F. SIGNAL



Note that, once again, the polarities of all frequencies have been reversed by the LO in the tuner, so that values in what looks like the lower sideband are shown as (+) quantities, and *vice versa*. It is better to put up with this awkwardness than to risk forgetting which of the sidebands in each system is partially suppressed, and which is transmitted in full.

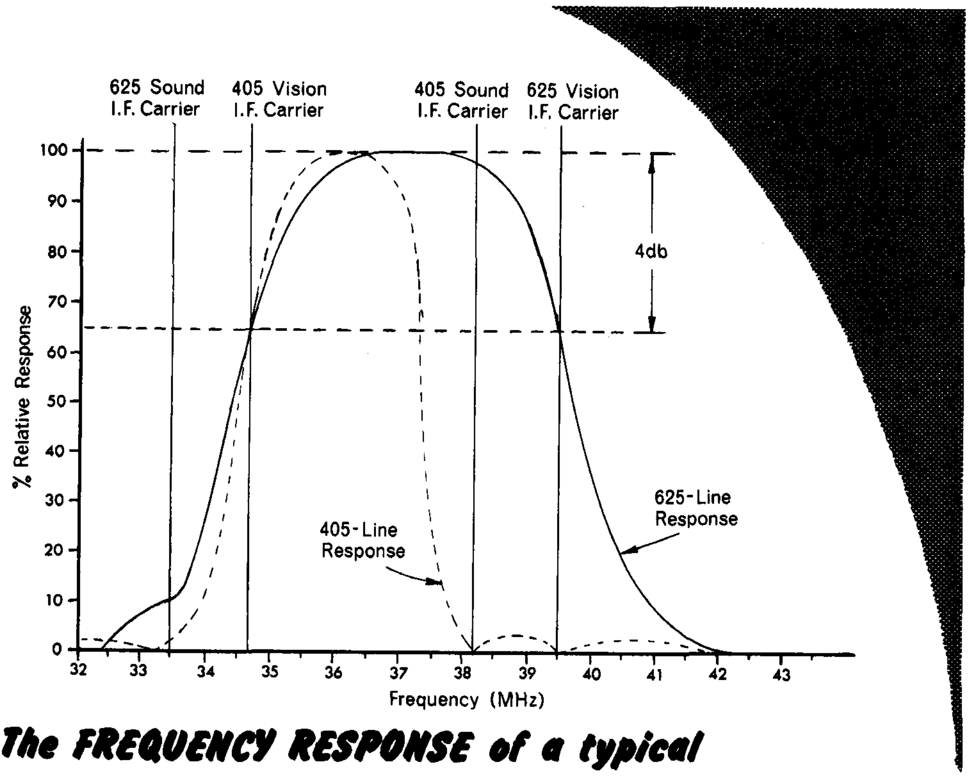
Observe the deviation in the desired linear fall of the frequency response curve at the frequency (33·5 MHz) of the sound i.f. carrier in the 625-line system. It is essential to keep the value of the sound signal *low* at this stage, lest it modulate the vision signal in the common amplifying stages through which both signals are soon to be put.

IF Amplifier A—The Frequency Response Curve in Practice

You have seen that two very different shapes are required for the frequency response curves of IF Amplifier A for the 405- and 625-line signals. Since the Dual-Standard Receiver must be able to accept signals on either line standard, it must either possess completely separate i.f. amplifiers for each, or else have common amplifying circuits whose frequency curves can be adjusted to suit the particular signal being received. For obvious reasons of simplicity, compactness and economy, the latter alternative is preferable if it can be achieved.

IF Amplifier A, as you know, has to handle signals which are very similar in frequency (405-line vision at 34·65 MHz; and 625-line vision at 39·5 MHz and sound at 33·5 MHz). It therefore cannot rely on wide frequency differences to select automatically the necessary tuned circuits when the viewer switches from one standard to another by rotating the *Standard Selection* control. What is needed instead is a response curve of the right shape to suit the wide bandwidth of the two UHF signals, together with means of narrowing and re-shaping the curve to the narrower bandwidth and different dimensions required by the VHF vision signal.

You will learn about the technical means used to achieve this in later pages. Here, meanwhile, is the variable response curve produced by a typical Dual-Standard Receiver of the present day (though you should note that a good many perfectly workable variations on the pattern also exist).



The FREQUENCY RESPONSE of a typical Dual·Standard I.F. Amplifier

IF Amplifier A—The Frequency Response Curve in Practice (*continued*)

The Dual-Standard i.f. amplifier whose actual frequency response is pictured on the page opposite is a wideband amplifier having an unrestricted bandwidth of 4·85 MHz extending from 34·65 MHz (the frequency of the VHF vision i.f. carrier) at one end to 39·5 MHz (the frequency of the UHF vision i.f. carrier) at the other. The response curve produced by the amplifier when the Receiver is switched to the 625-line standard is drawn in *solid unbroken* line in the diagram; while the curve produced when the receiver is switched to the 405-line standard appears as a *dotted* line.

Note how the curves differ from the theoretically desirable shapes shown in the illustrations on pages 2.92 and 2.93. It is quite possible to achieve more nearly the sharply angular response curves there shown. Indeed, much sharper curves are essential to the proper performance of, *e.g.*, a high-performance radar receiver. But the circuitry required to achieve them is too complex and costly to be installed in a mass-produced TV receiver whose price must be kept down to a figure which the public will pay. All commercial TV receivers involve many such compromises between the technically ideal and the economically possible; and response curves of the shape pictured opposite have been found to give results good enough to "get by" with the average viewer.

Note another important feature of these two response curves. In both of them the vision i.f. carriers occur at a point rather higher up their respective curves than the "half-way down from maximum amplification" which you would theoretically expect. In the curves shown, both carriers occur at about the point of 67% relative response, or "4 dB down from maximum".

The object of thus altering the theoretically ideal positions of the vision i.f. carriers on their respective response curves is to reduce an effect called *quadrature distortion* which is introduced in the vision detector in the process of handling a vestigial side-band transmission. The causes and cure of quadrature distortion are subjects frankly beyond the scope of this Series; but its effect is to cause *streaking* in the signals representing white (in systems using negative modulation) and in the signals representing black (in systems using positive modulation). In both cases the result is a noticeable loss of resolution.

It is possible to correct quadrature distortion by careful "counter-distortion" of the transmitted signal; but its harmful effects are also in practice reduced if the vision i.f. carrier is made to occur at a point rather higher up the response curve than it theoretically should.

The penalty to be paid is, as you will have guessed, some over-emphasis of picture detail compared with the "grey" background on the screen; but this has been found to give very little impression of unreality in practice.

When the viewer switches from the 625-line to the 405-line standard by operating the "*Standard Selection*" control on the front of his receiver, the 4·85 MHz width of the response curve of the amplifier is narrowed by compressing its high-frequency end, and by re-shaping its low-frequency end so as to get rid of the "10% bump" which you know is required by the 625-line sound i.f. carrier. The resulting bandwidth of about 2·85 MH (measured at the "4 dB down" points) is found adequate for the frequency content of the VHF signal.

The high-frequency end of the curve is brought sharply down to zero in the region of the 405-line sound i.f. carrier frequency in order to keep that signal out of IF Amplifier A.

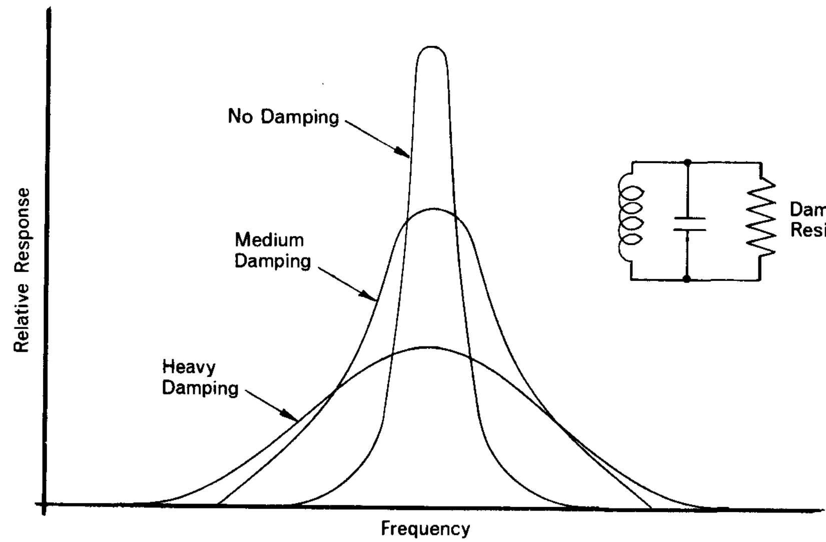
Shaping a Response Curve

The next step is to see how a response curve of unsatisfactory shape can be altered into something more desirable.

You already know that the frequency response of a tuned circuit can be varied by placing varying amounts of resistance across the circuit. Adding resistance to a circuit for this purpose is called *damping*, and the more heavily a tuned circuit is damped, the more is the curve of its output frequency flattened.

The illustration below shows the effect of damping of varying degrees of severity on an ordinary tuned circuit. You will see that, as damping is increased, so both the sharpness of tuning (*i.e.*, the selectivity, or Q, of the circuit) and the amplitude of its peak response are reduced.

On the other hand, the width of the response curve is increased, even though its extremities become too ill-defined to be (normally) of much use.



DAMPING a Tuned Circuit

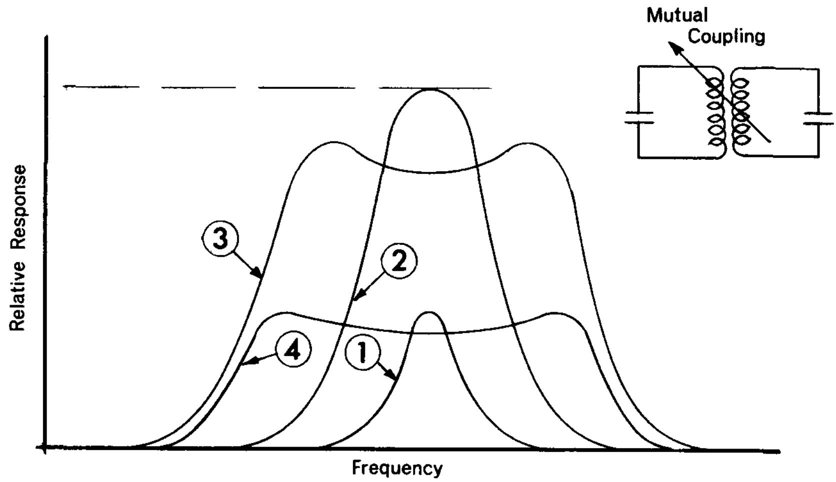
In other words, though damping techniques can be used for broadening a given response curve, the price to be paid is *loss of peak amplitude* and *loss of Q*.

Another method of altering the shape of a response curve to something more nearly what is desired is described on the page opposite. The illustration shows the effects of varying the *mutual coupling* of a pair of tuned circuits.

Physically, the mutual coupling of a pair of coils can be varied by moving the coils either closer together or farther apart. Alternatively (and more usually) it can be done by altering the positions of the two metal cores within a former on which both coils are mounted. In both cases the patterns of flux produced by the interacting magnetic fields of the two coils are altered by the movement.

Shaping a Response Curve (*continued*)

The frequency response shown in *Curve 1* in the illustration below results from a very weak (or "loose") coupling, produced either by the two tuned circuits being moved far apart or by their cores being moved away from their respective coils. The circuits are said to be *under-coupled,* and the amplitude of peak response is low.



The Effect of *varying the MUTUAL COUPLING* of Two Tuned Circuits

Curve 2 is produced by *critical coupling.* Again the response curve has a single peak, but it is steeper and of much greater amplitude than before.

If coupling is made closer still, the single peak of Curve 2 begins to broaden out into the double-humped *Curve 3.* This is now an *over-coupled* curve; and as over-coupling is increased, so the two humps become emphasized into two distinct peaks.

Curve 4 is produced by introducing resistive damping into the tuned circuits producing these two peaks. The overall amplitude of the curve is reduced, but its top is much flattened. A flat-topped, relatively steep-sided curve of this type is of excellent shape for use as a *band-pass filter.* It can be made to pass a fairly broad band of frequencies giving a near-equal degree of amplification to each, but its steep sides impose sharply defined limits to the band of frequencies passed.

If a near-rectangular shape of curve having a higher peak amplitude than Curve 4 can give is desired, it is possible to "fill in the valley" between the two humps of the over-coupled Curve 3 by means of a following stage of amplification having a single-peaked response curve whose amplitude is maximum at a frequency which coincides with that producing the valley in the preceding stage.

It is possible to produce response curves of almost any desired shape by means of the techniques described above, and by using (if necessary) a number of *cascaded* amplifying stages in the shaping circuit, each having a response curve carefully selected to play its part in producing a final curve of the exact shape required.

IF Amplifier A—Operation

You are now ready to study in detail the circuit diagrams of the two i.f. amplifiers used in the British Dual-Standard Receiver, and to follow out how each works.

Take, first, the one we have called **IF Amplifier A.** Its function is to amplify the VHF vision signal and also the sound and vision signals which are delivered to it from the UHF tuner on the 625-line standard.

The Amplifier consists essentially of two high-gain amplifying valves, plus a number of coupling transformers, plus also a number of rejector (trap) circuits which are switched into or out of circuit according to which line standard is being received at any given time.

The *Standard Selection* switch operates (as you know) at many points in the circuitry of the Dual-Standard receiver when the viewer turns or presses the appropriate control on his set. No fewer than five sections of it operate within the circuits composing IF Amplifier A. They are labelled S1–S5 in the circuit diagram on the page opposite.

Both the valves (V1 and V2) are of the frame-grid type and have very large values of mutual conductance (G_m)—typically greater than 13 mA/V. This high ability to amplify at the anode an input to the control grid enables the two valves to do a job which used to require three of the older type of pentode, whose values of G_m were no more than about 7·5 mA/V each.

Operation on the 405-line standard

All sections of the *Standard Selection* switch are set to their "405" positions, and S4 passes HT to the VHF tuner. The input signal to the Amplifier reaches S1 from the tuner (usually, you will recall, through a short length of coaxial cable forming part of the coupling between two bandpass coupling elements), and is applied to the junction between the capacitor C1 and the trap F3.

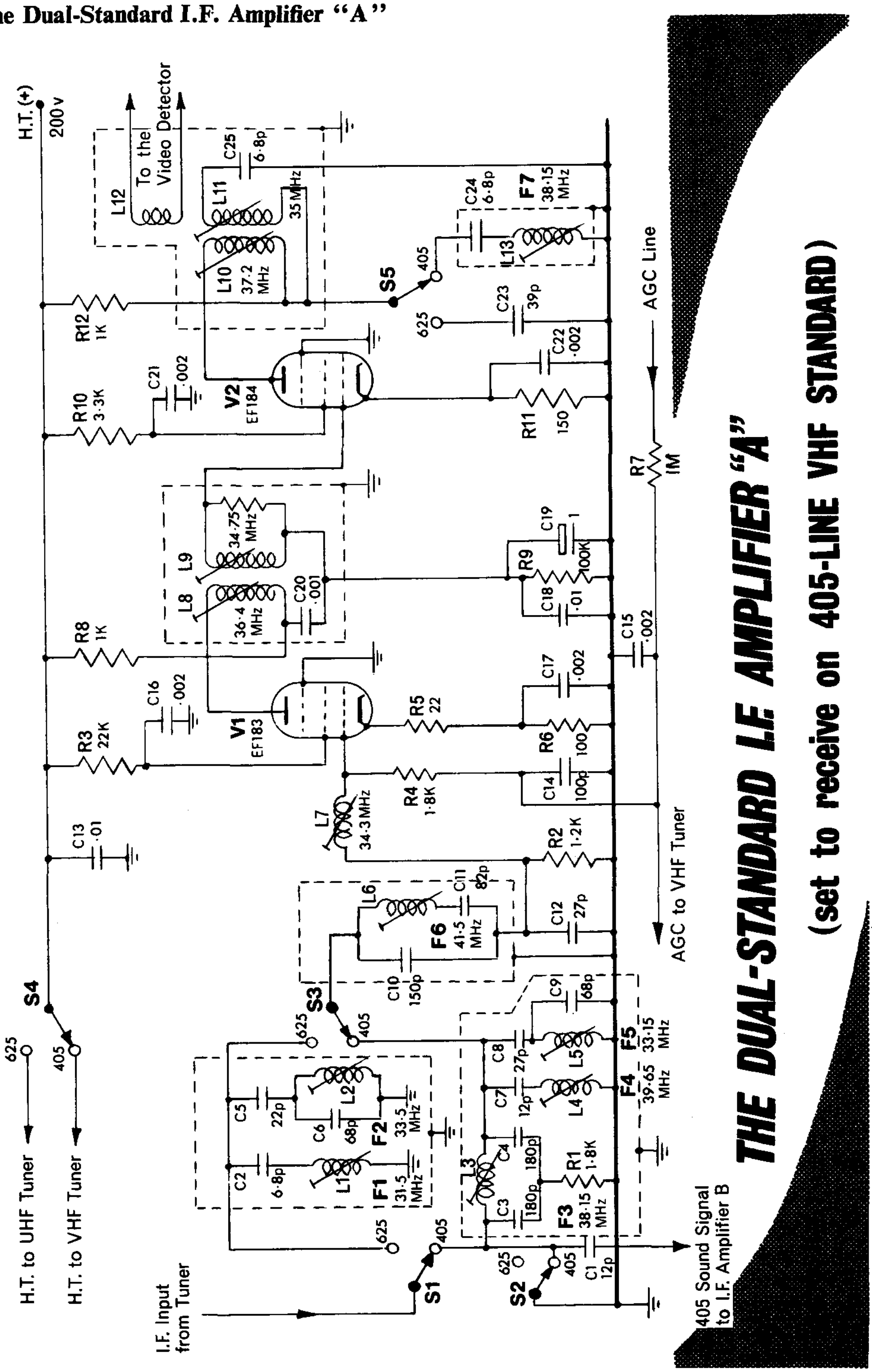
F3 is a bridged-T rejector circuit *tuned to resonate at the frequency of the sound signal* (38·15 MHz). It thus offers a very high impedance to this signal, and prevents it from reaching V1. Presented with this high Z in the direction of F3, the sound signal takes the path of much lower impedance through C1 and passes on its way to IF Amplifier B.

F3, however, offers very little impedance to a signal of the frequency of the VHF vision signal, which passes through it virtually unimpaired.

At the farther end of F3, the vision signal meets two more rejector circuits connected in shunt (F4 and F5), of which F5 is of the highly selective rapid-action type. F4 is tuned to resonate at 39·65 MHz, which is the frequency of *the vision signal in the upper adjacent channel.* (Channels on the 405-line standard are 5 MHz wide; 34·65 + 5 = 39·65 MHz.) A series-resonant tuned circuit such as F4 offers a very low impedance to a signal of the frequency to which it is tuned; so that the unwanted adjacent-channel interference is shunted away through F4 to earth, whereas the wanted vision signal passes unimpaired on its way.

F5 is tuned to resonate at 33·15 MHz, the frequency of *the sound signal in the lower adjacent channel* (38·15 − 5 = 33·15 MHz). Acting in the same way as did F4, it blocks or greatly attenuates this unwanted signal, while allowing the wanted vision signal to continue on its way through S3.

The Dual-Standard I.F. Amplifier "A"



THE DUAL-STANDARD I.F. AMPLIFIER "A"

(set to receive on 405-LINE VHF STANDARD)

IF Amplifier A—Operation *(continued)*

After S3, the vision signal encounters yet another rejector circuit, F6, this time a series-connected, parallel-tuned trap of the quick-acting type. F6 is tuned to 41·5 MHz, which is the frequency of the very powerful sound signal in Channel 1 of Band 1. This signal is often present at quite large strength despite the nearly 7 MHz difference between its frequency and that of the VHF vision i.f. signal; and it must be kept off the picture-tube of the receiver lest it spoil the picture.

Traps of the F6 type offer a very high impedance indeed to signals of the frequency to which they are tuned, but pass all other frequencies practically unimpaired.

The wanted vision signal next encounters the coil L7 which, with its own stray capacitances, forms a parallel-tuned circuit tuned to a frequency of 34·3 MHz. Though it does not look like it on the circuit diagram, L7 physically forms the second half of a bandpass coupling circuit whose first half is a similar tuned circuit in the output stage of the tuner.

This tuned circuit in the output stage of the tuner is tuned to resonate at a frequency of 37·15 MHz, with the result that the coupling circuit as a whole passes a bandwidth of some 2·85 MHz. As you learnt on page 2.95 (and saw on the illustration on page 2.94) this is the bandwidth which is required for good reception on the 405-line standard.

The reactance of the capacitor C12 contributes to the coupling between the two tuned circuits mentioned above.

The VHF vision signal is considerably amplified by V1, and is then developed across the primary (L8) of the bandpass transformer which forms its anode load. The tuned circuit formed by L8 and its stray capacitances resonates at 36·4 MHz; the secondary tuned circuit (L9 plus stray capacitances) resonates at 34·75 MHz.

From the secondary of this bandpass transformer the vision signal passes for further amplification in V2, from which it emerges at an amplitude of some 5 volts. V2 anode load is another bandpass transformer, formed by L10 and L11. L10, plus stray capacitances, resonates at 37·2 MHz: L11 (plus stray capacitances) at 35 MHz.

The two bandpass transformers (L8–L9 and L10–L11) together thus pass an overall bandwidth extending from 34·75 to 37·2 MHz. If this 2·45 MHz bandwidth had been achieved by use of a single bandpass transformer, the signal would have suffered an unacceptable degree of attenuation. The use of two such transformers provides an example of the type of cascading arrangement which you read about on page 2.97.

The two bandpass transformers in question are said to be "stagger-tuned" (see *Basic Electronics*, page 6.29). Together, they pass a bandwidth of the required width without undue loss of amplification.

The amplified signal appearing across L10 and L11 is inductively coupled to a tertiary winding (L12) on the same transformer, from which it is transferred to the Video Detector.

The primary winding L10, however, is also connected through S5 to another sound-rejector circuit, F7. Formed by C24–L13, this circuit is tuned to resonate at 38·15 MHz, the frequency of the sound i.f. on the 405-line standard. Any signal whose frequency lies at or near 38·15 MHz will therefore find an easy path to earth through F7. The presence in the circuit of F7 therefore serves to sharpen-up the high-frequency end of the response curve of IF Amplifier A (see page 2.94), and to prevent it trailing slowly away to zero in the way it is required to do on the 625-line standard.

IF Amplifier A—Operation *(continued)*

AGC voltage is applied only to V1 in this Amplifier A circuit. You will see later on, when you study how this voltage is generated, that it varies in value according to the strength of the received signal. Therefore, when the AGC voltage is fed to the control grid of V1 (through the low-pass filter formed by R7, C15 and the grid resistor R4), it affects the input capacitance of the valve as its own value varies. Some degree of negative feedback to compensate for this variation in input capacitance is provided by means of the undecoupled 22-ohm resistor R5 connected in series with the cathode bias components (R6–C17) of the valve.

AGC voltage is not applied at all to V2, for it is essential that this valve shall maintain a steady mean anode current in order to be able to handle the now-large vision signal without distorting the peak amplitude variations of the waveform. Any such distortion at this stage would be passed on as genuine by the video detector, and would impair the picture presented to the viewer.

Observe (at the foot of the circuit diagram on page 2.99) that the AGC voltage fed to V1 is the same voltage as that which you saw being fed to the tuner in the last Section.

Operation on the 625-line standard

When all sections of the *Standard Selection* switch are set to "625", HT is fed to the UHF Tuner through S4, and the input from the tuner is re-routed by S1. The capacitor C1 is shorted to earth by the action of S2 so as to prevent the 6 MHz intercarrier signal which is now present in the circuits of IF Amplifier B from intruding into the circuits of IF Amplifier A.

Remember that the UHF sound and vision signals remain unseparated all the way through IF Amplifier A. They first pass from S1 to the series-tuned rejector F1, which resonates at a frequency of 31·5 MHz. This is the frequency of *the adjacent-channel vision signal,* which at UHF occurs 8 MHz below the 39·5 MHz frequency of the vision signal itself. F1 offers very low impedance to a signal of its own resonant frequency, so the interference is virtually shorted to earth.

The next rejector, F2, performs an important special function on this line standard. This is *to reduce the level of the sound component of the combined UHF signal* by as much as 20 dB, thus lowering it *to only about 10% of its former value.* This needs to be done before any amplification of the two signals takes place; for a too-large element of sound can easily impose unwanted modulations on the vision signal as the two signals pass through their common amplifying stages. This would cause a kind of distortion known as *cross-modulation,* which cannot be corrected at a later stage.

To do its job, F2 (a series-connected trap of the rapid-action type) is tuned to resonate at the 33·5 MHz frequency of the wanted sound signal. If the efficiency of the trap were perfect, the sound signal would be suppressed altogether; but sufficient circuit losses are deliberately built into the design of the filter to provide an overall signal attenuation of only about 90%.

After passing F1 and F2, the two UHF signals reach the rapid-action rejector F6, which (you will recall) used its resonant frequency of 41·5 MHz to block the intrusive sound signal in Channel 1 when the Receiver was set for 405-line reception. It now uses this frequency to offer a similarly high impedance to *the sound signal in the upper adjacent channel,* which at UHF lies 8 MHz above the 33·5 MHz frequency of the sound signal itself.

IF Amplifier A—Operation ***on the 625-line Standard*** *(continued)*

You saw at the foot of the last page that the job of F6 is to block the 41·5 MHz sound signal in the upper adjacent channel. It is far more important to suppress this intruding sound signal when the receiver is set to 625-line operation than it was on 405 lines, because the unwanted frequency now lies much closer to the all-important vision i.f. of 39·5 MHz. *Hence the much greater importance of F6 at UHF.*

After passing F6, the signal is handled in the same way as was the 405-line vision signal until it has received its double measure of amplification in the two valves and has been developed across the transformer L10.

On "625", however, the sound rejector F7 is disconnected by S5 from the "earthy" end of L10, and its place is taken by the 39 pF capacitor C23. The purpose of this is to allow the bandwidth of the transformer to open out to its full width, and its high-frequency end to decay appreciably more slowly than it did on "405" (see illustration on page 2.94).

The output signals (the UHF vision and sound i.f.'s) are again taken from the tertiary winding (L12) to the Video Detector.

The purpose of the little group of components R9–C18–C19 in the grid circuit of V2 is to prevent a phenomenon known as *AGC blocking*, which you will learn more about when you study the vision AGC circuit. Briefly, it can occur when a sudden large signal is applied to the Video Detector, resulting in a loss of AGC to IF Amplifier A and a corresponding excessive flow of current through V2 (and through certain other valves in the receiver as well).

The danger is met by the combination R9–C19, the working of which will be explained in the Section explaining Automatic Gain Control.

The very-small-value capacitor C18 serves to counteract the inductive properties which the large-value capacitor C19 begins to acquire at frequencies as high as those handled in this Amplifier. At these frequencies, large-value capacitors of the electrolytic type tend to behave as much like coils as like capacitors; and it becomes necessary to nullify this effect by connecting in parallel with the electrolytic capacitor another, much smaller, capacitor whose value of inductance, even at these frequencies, is almost zero.

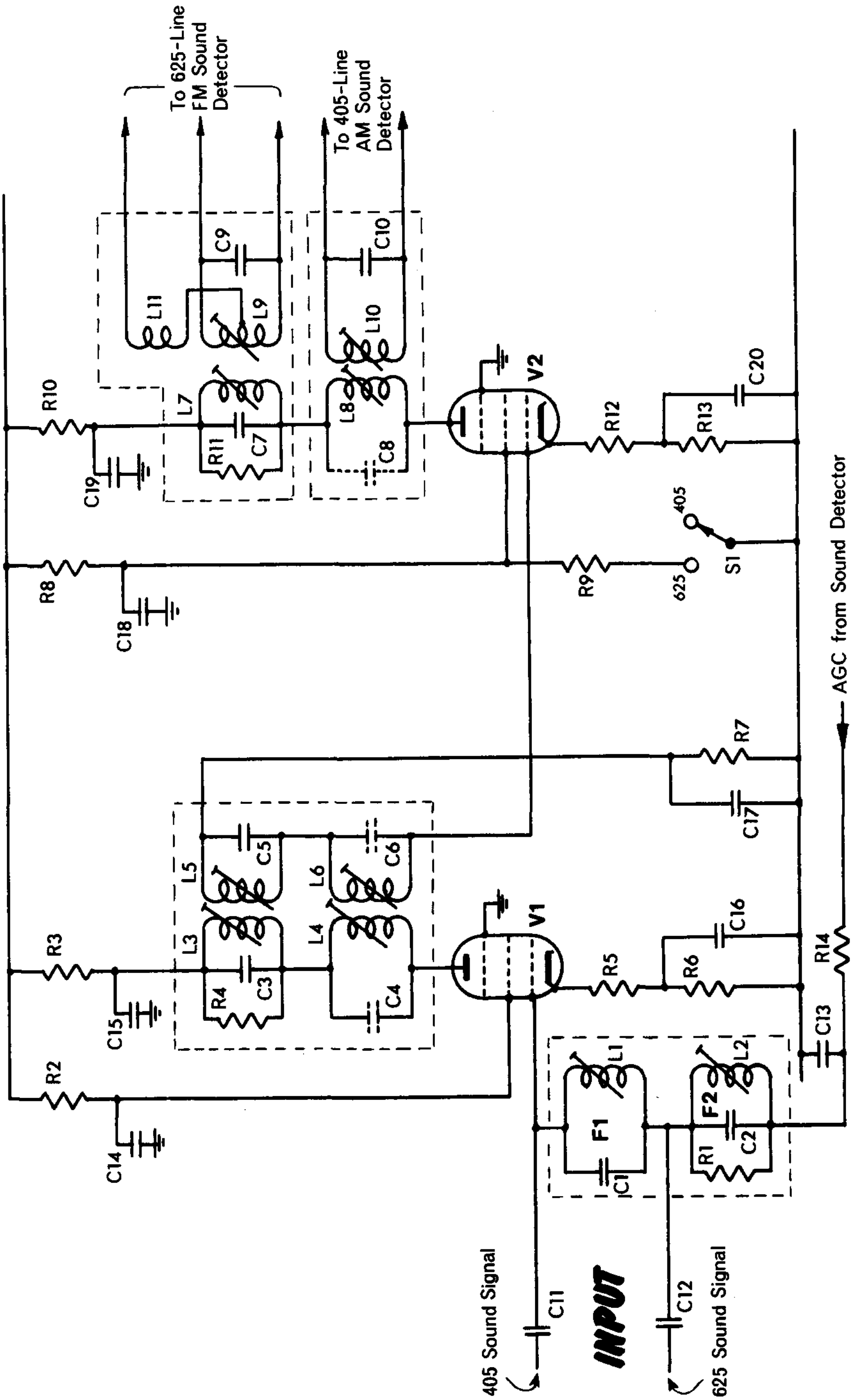
IF Amplifier B—Operation

The full circuit diagram of **IF Amplifier B** is shown on the next page, and the working of the circuit is explained on the pages following.

IF Amplifier B is a *sound amplifier only*. Its inputs are the 38·15 MHz sound signal of the 405-line system (which you saw being separated from its vision signal by the rejector circuit F3 in the circuit diagram on page 2.99), and the intercarrier signal of 6 MHz frequency which you have been told is fed back from the Video Detector to IF Amplifier B in the 625-line system.

This intercarrier signal, as you will learn later on, is a "beat frequency" derived from the heterodyning of the *amplitude-modulated* vision i.f. signal with the *frequency-modulated* sound i.f. signal. The intercarrier therefore carries modulating components from both signals, being amplitude-modulated by the vision i.f. carrier and frequency-modulated by the sound i.f. carrier. It is the sound signal that interests you in IF Amplifier B, and the amplitude modulations imposed on the intercarrier signal by the vision i.f. carrier are a nuisance which must be suppressed.

The Dual-Standard I.F. Amplifier "B"



Circuit Diagram of *I.F. AMPLIFIER "B"* in the Dual-Standard Receiver

IF Amplifier B—Operation (*continued*)

The reason why the amplitude modulations imposed on the 6 MHz intercarrier signal are a nuisance which need to be suppressed is this. You will recall from *Basic Electronics*, pages 6.32 and 6.33, that a commonly-used way of deriving an audio signal from a frequency-modulated carrier is to use a *frequency discriminator* circuit, and that such a discriminator is very sensitive to variations in the amplitude of the signal. If these are not adequately suppressed, the discriminator will reproduce them as a form of noise on the audio signal which (in this method of signal processing) is known as *intercarrier buzz.*

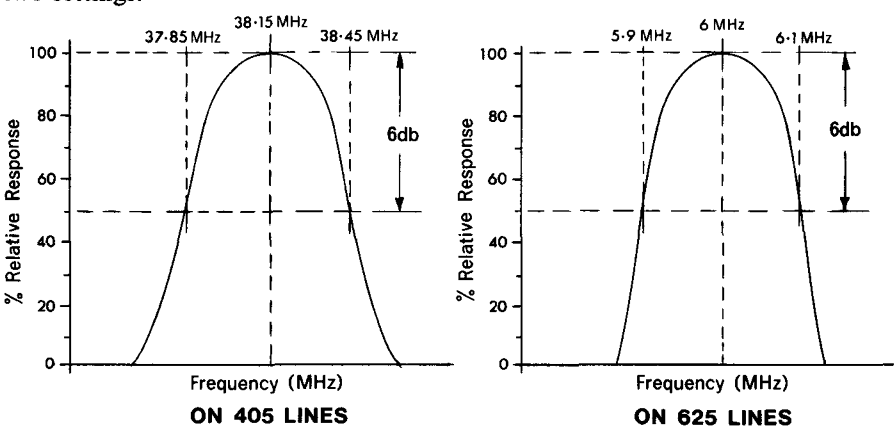
IF Amplifier B must therefore provide circuitry capable of sharply limiting the amplitude of i.f. carrier variations when the receiver is switched to "625".

IF Amplifier B needs little help from the *Standard Selection* switch to perform its function as a dual-frequency tuned amplifier. This is because of the big difference between the two frequencies (38·15 MHz and 6 MHz) which it has to handle.

To frequencies as widely separated as these, the same tuned circuit reacts in very different ways. It is therefore possible to connect in series two parallel-tuned circuits, each resonant to one of the desired frequencies, and to pass signals on either line-standard through the combination. Each tuned circuit blocks the frequency to which it is tuned, but behaves like a very low capacitive or inductive reactance to the other frequency passing through the combination, so having almost no effect on it.

If, therefore, you have two signals of widely different frequency, it is only a matter of feeding the two signals into the appropriate part of the double trap, and you are bound to be able to pass one signal and to block the other. You will see the technique in action shortly.

The frequency responses required from IF Amplifier B are very similar in shape whether the receiver is switched to "405" or to "625", though the frequencies themselves (and the bandwidths) are of course different. The illustration below shows side-by-side the response curves produced by a typical sound IF Amplifier on each of its two settings.



FREQUENCY RESPONSE of a typical SOUND I.F. AMPLIFIER

Note that the bandwidth of the 405-line curve is a full 600 kHz at the two points "6 dB down from maximum amplification".

IF Amplifier B—Operation (*continued*)

So wide a bandwidth as 600 kHz for the 405-line curve seems at first sight surprisingly large. Few people can hear audio frequencies higher than 15 kHz, so that the sideband frequencies created by the audio signal need seldom exceed $\pm$ 15 kHz above and below the frequency of the carrier which it is modulating. A bandwidth of little more than 30 kHz would therefore seem quite adequate.

At "625", it is true, a bandwidth of at least 100 kHz is essential to accept the $\pm$ 50 kHz frequency deviations of the i.f. carrier caused by the AF modulations superimposed upon it; but a bandwidth of 600 kHz on "405" seems far wider than is needed.

Two significant advantages, however, plus a third potential advantage, arise from using so wide a bandwidth. First, the effects of frequency drift in the local oscillator in the tuner are almost eliminated (if LO frequency drifts, so will the intermediate frequency which it produces when it beats with the incoming signal). This is particularly important when the receiver is operating in Band 3, where the frequencies involved are comparatively high. A small percentage shift in a Band 3 frequency can easily amount to 200 kHz, so it is highly desirable that the i.f. carrier should have room in which to drift a bit *within* the available bandwidth.

The second advantage of a wider bandwidth is that the shape of sundry noise pulses is thereby kept sharply defined, which makes their rejection in a later stage much easier.

The third (potential) advantage is that the quality of the sound reproduction could be made greatly superior to that of the ordinary AM sound radio receiver, whose transmission bandwidth is restricted by international agreement to about 10 kHz only. Few TV receivers exploit this potential advantage, however, for reasons of cost; and quite low-quality output transformers and loudspeakers are in fact standard fittings.

Now look at the circuit diagram of IF Amplifier B on page 2.103. Of the two valves shown, V1 is a high-gain pentode of frame grid construction, V2 a pentode of the normal type.

The amplifier has two input terminals, for its input signals come (as you know) from two different sources. When the *Standard Selection* switch is set to 405-line operation, the "625" intercarrier signal is not generated at all. Nor is the 405-line sound i.f. generated when the receiver is set to "625".

For operation on the 405-line standard, the 38·15 MHz sound i.f. signal is applied to the grid of V1 via the capacitor C11. Two parallel-tuned circuits, L1–C1 and L2–C2, form two filters (F1 and F2) which are connected in series with one another and in shunt with the incoming signal. Together, they form the "trap combination" you read about on page 2.104.

F1 is tuned to resonate at 38·15 MHz, F2 at 6 MHz. To a 38·15 MHz signal F1 therefore offers very high impedance, while to the same signal F2 acts as no more than a very low capacitive reactance. Thus the "405" signal is developed across F1, while F2 connects the lower end of F1 to earth through the even lower reactance of the AGC decoupling capacitor C13.

Two similar series-connected, parallel-tuned circuits form the anode load of V1. The one nearest the anode, L4–C4 (with C4 actually the stray capacitance of the L4 circuit) is tuned to accept the "405" signal. It also, in combination with L6–C6, forms a coupled circuit passing a bandwidth of some 600 kHz distributed about a centre frequency of 38·15 MHz (L4–C4 having a resonant frequency of about 37·85 MHz and L6–C6 a resonant frequency of about 38·45 MHz).

IF Amplifier B—Operation *(continued)*

L3–C3 and L5–C5 (whose resonant frequencies are 5·9 MHz and 6·1 MHz respectively) form a similar bandpass coupled circuit for the "625" signal, having a 200 kHz bandwidth centred on 6 MHz. At 38·15 MHz, however, they behave as very low capacitive reactances, and so offer low impedance to the "405" signal.

The effective anode load of V1 is therefore the high impedance of L4–C4. The amplified "405" signal is developed across this impedance, and is fed to the grid of V2 by the transformer action of L6–C6 and through the low series-connected reactance of L5–C5.

The switch S1 is operated by the *Standard Selection* control. In the "405" position, it open-circuits resistor R9 so that the screen grid of V2 is connected to the HT line through R8. Connected in this way, V2 behaves as a straightforward amplifier (just as does V1, whose screen grid is connected to HT through R2).

C14 and C18 are decoupling capacitors for the screen grids of V1 and V2 respectively. R7 and C17 come into play on "625" only.

The anode load of V2 consists of tuned transformers working exactly as did the anode loads of V1, save that the secondaries of the two transformers are differently connected. L8–C8 and L10–C10 form the "405" tuned transformer, with its secondary taken to the AM sound detector. Conversely, L7–C7 and L9–C9 resonate to the 6-MHz frequency of "625" operation, with their output being taken to the FM sound detector with the aid of a tertiary winding, L11.

R3–C15 and R10–C19 are the normal decoupling components for the HT supply.

AGC voltage is derived from the 405-line sound detector only, not being needed for the frequency-modulated 625-line signal. It is applied to V1 grid via R14, which is decoupled by C13.

The resistors R5 and R12 in the cathode circuits of V1 and V2 respectively operate as undecoupled negative-feedback resistors serving to offset changes in the input capacitances of the two valves. Such changes are often caused by variations in their respective gains, either from AGC or by reason of valve ageing.

The other components in the cathode circuits of the two valves (R6–C16 and R13–C20) are there to provide normal cathode bias.

When the receiver is set for 625-line operation, all those tuned circuits in the grid and anode circuits of both valves which are tuned to resonate at 38·15 MHz behave as low-value inductive reactances when signals of 6 MHz frequency are applied to them. The 6 MHz tuned circuits, on the other hand, now offer high *Z* to the signal and function as the grid and anode loads respectively.

The intercarrier input is applied to the amplifier circuit through the capacitor C12, and is developed across the resonant circuit F2. The resistor R1 connected across this circuit provides the damping needed to give the required bandwidth. Similar damping resistors (R4 and R11) are connected across the "625" anode loads of V1 and V2.

The main point of interest in the circuit is that V2 is now connected as an "over-driven amplifier" so that it acts effectively as an amplitude limiter to the "625" signal. What happens is that, when S1 is moved to the "625" position, R9 is brought into circuit so as to form, with R8, a potential divider across the HT supply. The positive voltage applied to the screen of V2 is thus reduced, and this in turn reduces the grid base of the valve.

IF Amplifier B—Operation (*continued*)

You will remember from *Basic Electronics* that the "grid base" of a valve is the range of grid voltage which extends from that at which anode current is cut off to that at which grid current starts to flow. A reduced grid base for V2 therefore means that even a small variation in the amplitude of the signal applied to its grid will cause the valve to overload and cut off.

The amplified output signal will thus be limited to a nearly constant amplitude, a condition which you know to be desirable for the proper operation of the detector circuit in the next stage. (This is true even though the type of detector actually used in that stage is one that is relatively insensitive to amplitude variations, as you will find is the case.)

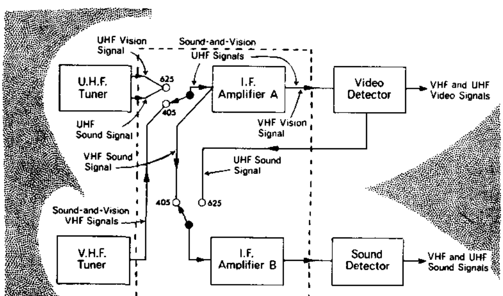
The limiting action of V2 is reinforced by the "leaky-grid" bias afforded by the two components C17 and R7. When the application of a positive signal to the control grid of V2 causes grid current to flow in the valve, electrons flow on to the upper plate of C17 through L6 and L5, and the capacitor charges negatively. When the valve cuts off, the charge on C17 leaks away across R7; but this resistor is of such a value that leak-away occurs only slowly.

Thus a nearly steady negative bias is maintained on the control grid of V2, which also helps to limit the amplitude of the amplified "625" signal.

REVIEW of the Intermediate Frequency Amplifier

The principal function of the IF Amplifier in the British Dual-Standard receiver is to raise the amplitudes of the sound and vision intermediate-frequency signals leaving the two tuners (VHF and UHF) until they become large enough to activate the Sound and Video Detector stages.

The ways in which the sound and vision signals are processed in the IF Amplifier stage are completely different in the VHF and UHF systems.



Block Diagram of the I.F. AMPLIFICATION STAGE in the British Dual-Standard Receiver

REVIEW of the IF Amplifier (*continued*)

On 405-line operation, **the sound and vision signals are separated as soon as they leave the VHF tuner. The vision signal then receives its i.f. amplification in what has been (unofficially) christened in this Section** ***IF Amplifier A,*** **while the sound signal receives its own degree of i.f. amplification in the completely separate** ***IF Amplifier B.***

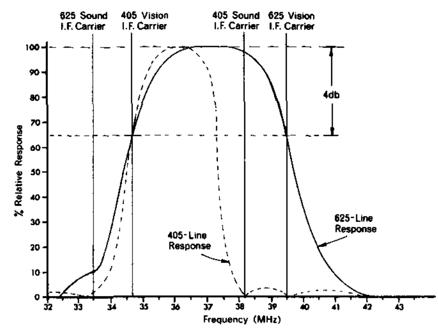
This is called the ***split-sound*** **method of signal processing.**

On 625-line operation, **the sound and vision signals coming from the UHF tuner are amplified** ***together*** **in IF Amplifier A, and are not separated until they reach the Video Detector. They are there caused to beat together to produce a 6 MHz** ***intercarrier*** **signal of constant amplitude, which carries the signal content of the sound signal in the form of small frequency deviations about the 6 MHz beat frequency.**

The UHF vision signal continues on its way through the Video Detector, but the intercarrier bearing the UHF sound signal is taken back to the input of IF Amplifier B. It then receives its due measure of i.f. amplification in IF Amplifier B before travelling on to the Sound Detector stage.

This is called the ***intercarrier*** **method of signal processing.**

Frequency Response—IF Amplifier A. **The frequency response curve of IF Amplifier A needs to be re-shaped, and its width increased, every time the Dual-Standard receiver is switched from VHF to UHF. The reasons are: (*a*) the different transmission band-widths of the two systems, (*b*) the fact that the two carriers are modulated with opposite polarity, and (*c*) because in the 405-line system it is the** ***upper*** **sideband which is partially suppressed, whereas in the 625-line system it is the** ***lower.***



The FREQUENCY RESPONSE of a typical Dual-Standard I.F. Amplifier

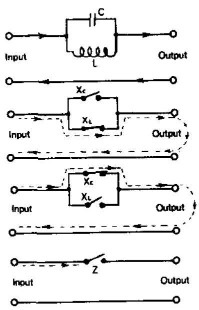
The other important functions of the IF Amplifier are to improve the overall selectivity of the receiver, and to prevent the wanted sound and vision i.f. signals from being impaired by either second-channel or adjacent-channel interference.

REVIEW of the IF Amplifier (*continued*)

Rejector circuits, **or** ***traps*****, are used (*a*) to change the shape of the frequency response curve of IF Amplifier A, (*b*) either to shunt unwanted signals away from the path of the desired signals throughout the vision i.f. amplifier stage or to block them off it, and (*c*) to separate the 405-line sound and vision signals from one another at the input to IF Amplifier B.**

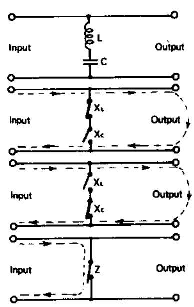
Many kinds of trap exist but all are made up of varying combinations of *L*, *C* and *R*. The types most commonly used in the TV Receiver are these:

C



A *parallel resonant* rejector connected *in series* with the signal path *BLOCKS* an unwanted signal when the resonant frequency of the rejector is made equal to the frequency of the intruding signal.

D



A *series resonant* rejector connected *in parallel* with the signal *SHUNTS* an unwanted signal away from the signal path when the resonant frequency of the rejector is made equal to the frequency of the unwanted signal.

This latter technique is also known as *signal absorption*.

§13: THE SOUND SIGNALS

It will be convenient now to take the two sound signals (VHF and UHF) from their common IF Amplifier right through to the loudspeaker, even though you have not yet seen how the 6 MHz intercarrier carrying the UHF sound signal is generated in the Video Detector. All the other circuitry involved will be familiar to you from your work in *Basic Electronics*; and it will simplify future explanations if there is no need to worry much more about what happens to the sound signals in the British Dual-Standard Receiver.

Remember what were the two output signals from IF Amplifier B:

405-line (VHF): An i.f. carrier of 38·15 MHz, *amplitude-modulated* by the 405-line sound signal.

625-line (UHF): An i.f. carrier of 6 MHz, *frequency-modulated* by the 625-line sound signal.

These two frequencies are so widely separated that there is no great difficulty in keeping each signal out of the detector circuits designed for the other.

The circuit diagram on the page opposite is that of the sound detector stage of a typical receiver capable of operating on both the 405-line and the 625-line systems. Note that all that part of the circuit lying *to the left of the heavy vertical dotted line* has already appeared as the right-hand portion of the circuit diagram on page 2.103. This will explain the apparent absence of inputs in the circuitry shown.

Lighter dotted lines surround the circuits handling the UHF and the VHF signals respectively. Physically, the greater part of each detector circuit is located within the screening can containing the tuned transformer to which it is related in the anode circuit of the second i.f. amplifier valve in IF Amplifier B. (These tuned transformers are labelled L7–L9 for the UHF signal, and L8–L10 for the VHF signal, in the illustration on page 2.103.)

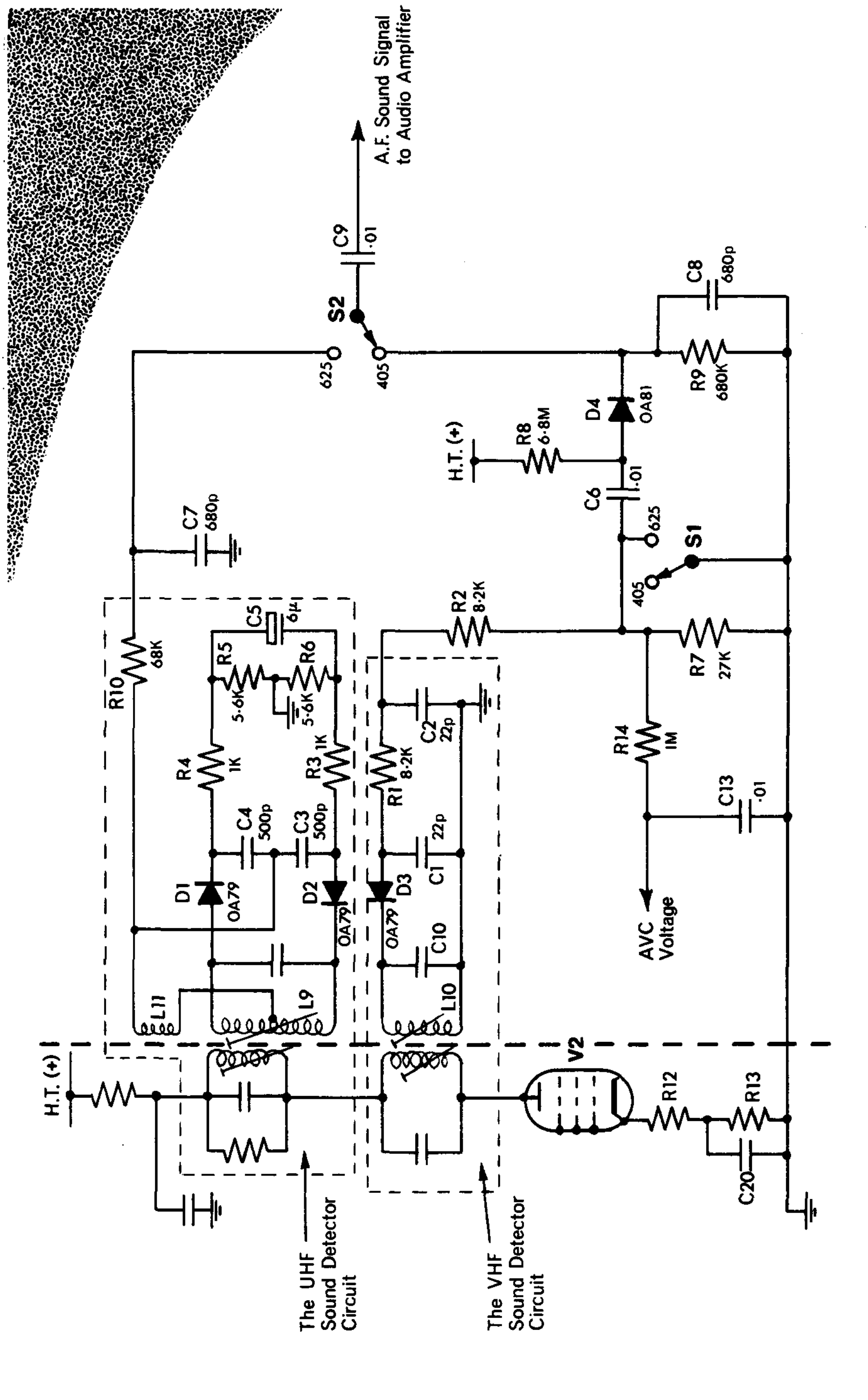
Detecting the VHF Sound Signal

Take first the detection of the VHF sound signal. You will recall from page 5.29 of *Basic Electronics* that the essential stages in the process of detecting the audio-frequency content of an AM signal are: (*a*) the **rectification** of the i.f. signal into pulsating d.c.; (*b*) the **filtering out** of the i.f. component of the rectified signal, leaving only its audio-frequency component; (*c*) the **amplification** of this a.f. component to a value suitable for (*d*) its **reproduction** as audible sound in the loudspeaker.

In the circuit diagram opposite, the 405-line detector (D3) is a normal half-wave diode detector of the semiconductor type, so connected as to pass only the negative-going half-cycles of the signal. These cycles, in the form of negative-going pulsating d.c., then encounter the low-pass filter formed by C1, C2 and R1 whose purpose is to remove the residual i.f. component from the signal. The filter passes to earth signals of all frequencies higher than those detectable by the human ear (the audio-frequency range for most people is of the order of 15 kHz). Thus it is only the negative-going half-cycles of a wave having the comparatively long wavelength characteristic of the audio-frequency range which can get past the filter to be developed across R7.

The resistor R2 is connected into the circuit so as to form, with R7, a potential divider across the output of the detector. This reduces the loading placed on the detector by subsequent circuitry—especially by the interference-limiter circuit formed by R8, D4, R9 and C8.

The Sound Detector



The SOUND DETECTOR in a typical DUAL-STANDARD RECEIVER

Detecting the VHF Sound Signal *(continued)*

Across R7 there are two paths for the signal to take. One is through R14, a relatively large (1 M) resistor, to be developed across the 0·1 mfd capacitor shown as C13 on the illustrations on pages 2.103 and 2.111. This is an AGC voltage whose purpose is to ensure that the gain of V1 (*see page 2.103*) remains reasonably constant whenever the amplitude of the received signal varies. What happens is that this AGC is caused to follow, by means which will be explained in a later Section, not the variations of the individual half-cycles of the audio signal, but *the mean value of these variations throughout the period of transmission.* As the strength of the received signal (*e.g.*) increases, so does the mean value of the (negative) AGC voltage. More negative bias is applied to the grid of V1, and the gain of the valve is reduced.

Similarly, if the received signal should start to fade, the mean value of the negative AGC voltage would be reduced, less bias would be applied to the grid of V1, and the gain of the valve would increase to offset the falling value of the signal.

The other direction which the audio signal across R7 can take is through C6 to a second semiconductor diode, D4.

The purpose of D4 is to act in conjunction with R8, R9 and C8 as an interference-limiter circuit, smoothing out (and if possible eliminating) the effect on the signal of unwanted noise. Noise pulses derive from such sources as motor-car ignition systems, electric drills and the like. They are typically of short duration and very steep-sided—in other words, they contain very high-frequency components in their make-up. You will remember that great care has been taken in previous circuits (especially by giving IF Amplifier B a much wider bandwidth than it theoretically needs) to preserve the shape of these intruding noise pulses without distortion, so that they can be satisfactorily eliminated at a later stage. That is what is about to happen to them now!

When no signal from C6 is present, D4 is forward-biased by the positive voltage applied to it from HT (+) through R8. The internal resistance of a forward-biased diode is no more than a few hundred ohms, so that the diode in this condition represents only a low resistance between the two resistors R8 and R9. These two thus form a potential divider, and the capacitor C8 charges to a voltage determined by their relative values. The actual value of this charging voltage is not of great importance, but is approximately equal to the value of the expression $R9/(R8 + R9) \times V_{HT}$.

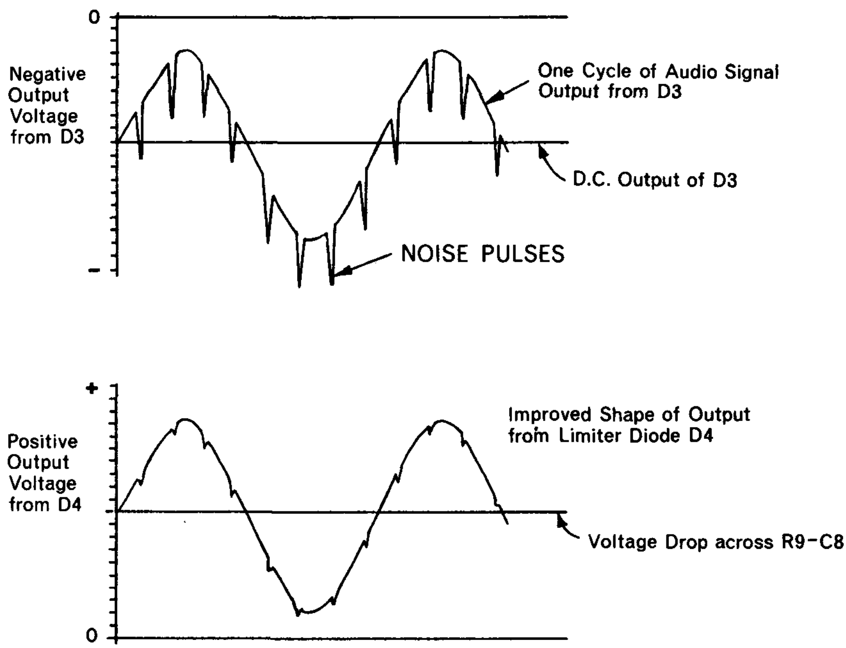
Now assume that an audio signal, varying in amplitude according to the modulation applied to it at the transmitter but carrying no attendant noise, reaches D4 through C6. The frequency of the variations in this signal will be quite low—well within the audio-frequency range of 15 kHz. Within this audio range, the voltage developed by C8 is able to follow accurately the voltage fluctuations of the incoming signal, *but cannot do so for any signal whose frequency varies any faster.* This is achieved by careful selection of the values of R2, R7, R8, R9 and C8, so that the time constant and the charging resistance of C8 can be precisely adjusted.

With C8 able to follow the fluctuations of the signal when it has no appreciable content of noise, D4 remains forward-biased. You know that, when a diode is conducting normally, the polarities of both its terminals move "up and down" in unison, so the diode presents itself to the signal as a closed switch. The audio signal is therefore satisfactorily developed across C8, and passes via the *Standard Selection* switch S2 and the coupling capacitor C9 to the Audio Amplifier.

How the VHF Interference Limiter Works

Now suppose that the audio signal reaching D4 has impressed upon it sudden noise pulses of large amplitude. Pulses of this shape and duration are over and done with much too fast for the charge on C8 to be able to follow them. So while the left-hand terminal of D4 will be driven rapidly negative by the large negative noise signals arriving from the detector diode D3, its right-hand terminal will be unable to follow and will therefore be *less negative* than its fellow for the duration of the pulse. With the right-hand terminal effectively positive with respect to the left-hand one, the diode becomes reverse-biased. In this condition it will not conduct, and the noise pulse is blocked.

In practice, of course, blocking is never perfect; and the illustration below gives an idea of the approximate extent to which the effect of noise pulses is reduced by the action of a typical interference limiter.



HOW THE INTERFERENCE LIMITER REDUCES Noise

Take care, by the way, to distinguish the interference limiter circuit represented by D4–R8–R9–C8 from the simple type of limiter circuit you learnt about in *Basic Electronics,* whose function was to limit the amplitude variations of an FM signal so as to allow its frequency variations to be satisfactorily converted into an audio signal.

Detecting the UHF Signal

When the receiver is set to operate on 625 lines, the output from the VHF detector, including its AGC line, is short-circuited to earth by the switching of S1 to its "625" setting; while the similar switching of S2 disconnects the interference limiter and ensures that the audio output signal is taken only from the UHF sound detector circuitry.

The detector used is of the **ratio detector** type which you learnt about on pages 6.41 and 6.42 of *Basic Electronics*. The principal advantage of this type of detector is that it is relatively insensitive to variations in the amplitude of the incoming signal. There is therefore no need for an additional amplitude limiter in the detector circuitry (*see foot of last page*) to remove the amplitude variations which normally need to be eliminated from an FM signal before it can be satisfactorily detected. In any case, as you already know, V2 is connected as an overdriven amplifier when the receiver is set for 625-line operation, and so in itself acts as a limiter to reduce the sharp variations of amplitude which are present on the 6 MHz intercarrier. Without this limiting action of V2, the picture reproduced on the screen would almost certainly be impaired by intercarrier buzz, for not even the ratio type of detector can give perfect rejection of amplitude variations.

Glance back now to the circuit diagram on page 2.111 and you will see that the detector consists of the two oppositely-connected semiconductor diodes D1 and D2, with their associated circuitry C3–C4–R3–R4–R5–R6–C5. Compare this layout with that shown on *Basic Electronics* page 6.41 (which had valve diodes instead of semiconductor ones), and you will have no difficulty in seeing how the detector works. C5, of course, is the capacitor across which it is essential to maintain a constant voltage.

The audio-frequency output from the detector is taken from the junction of C3 and C4 through the combination R10–C7. The values of R10 and C7 are so chosen that they form a *de-emphasis filter* having a time-constant of 50 microseconds. Their function is to counteract the 50 μs pre-emphasis given (as you know) to the signal at the transmitter with the object of increasing the gain of the transmitter's audio amplifier at the higher audio frequencies. (For **pre-emphasis** see *Basic Electronics* page 6.15; for **de-emphasis,** page 6.45.)

The Audio Amplifier and Loudspeaker

When they emerge from the sound detector circuitry, the VHF and UHF signals are both of audio frequency. The same circuits can therefore be used to handle them from now on. These circuits are shown in the illustration opposite.

The input to the audio amplifier is derived from the capacitor C9, which is the same component as the one similarly labelled in the illustration on page 2.111.

The heart of the audio amplifier is a single valve of the triode-pentode type, with the triode section functioning as a simple **voltage amplifier** feeding the pentode **power amplifier.** The signal is developed across the anode load (R2) of the triode, and is taken to the grid of the pentode through C2 and R5.

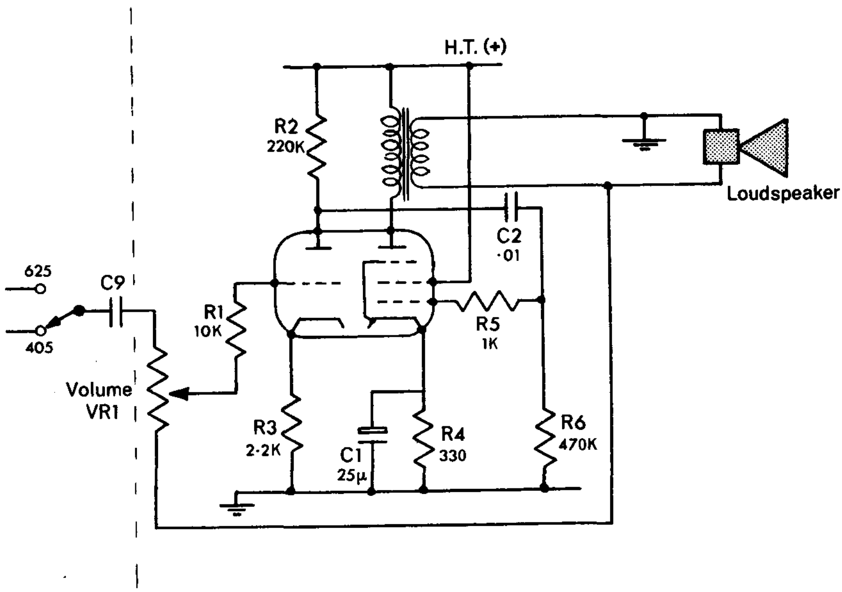
The lower end of the Volume Control VR1 (which the viewer can adjust to his convenience) is taken to earth through the secondary winding of the transformer which forms the anode load of the power amplifier. This arrangement provides some degree of negative feedback to the grid of the triode, so helping to improve the overall frequency response of the audio amplifier circuitry.

The Audio Amplifier and Loudspeaker (*continued*)

A similar function is performed by the undecoupled resistor R3 in the cathode circuit of the triode, which also provides negative feedback.

The loudspeaker itself is generally of the moving-coil type described on pages 2.89 to 2.96 of *Basic Electronics*, Part 2, and thus needs no further description here.

THE AUDIO AMPLIFIER AND OUTPUT STAGE



§14: THE VIDEO DETECTOR

Having been duly amplified by IF Amplifier A, the vision signal is now of sufficient size to operate the video detector. This stage generally requires an input signal of a few volts for efficient operation.

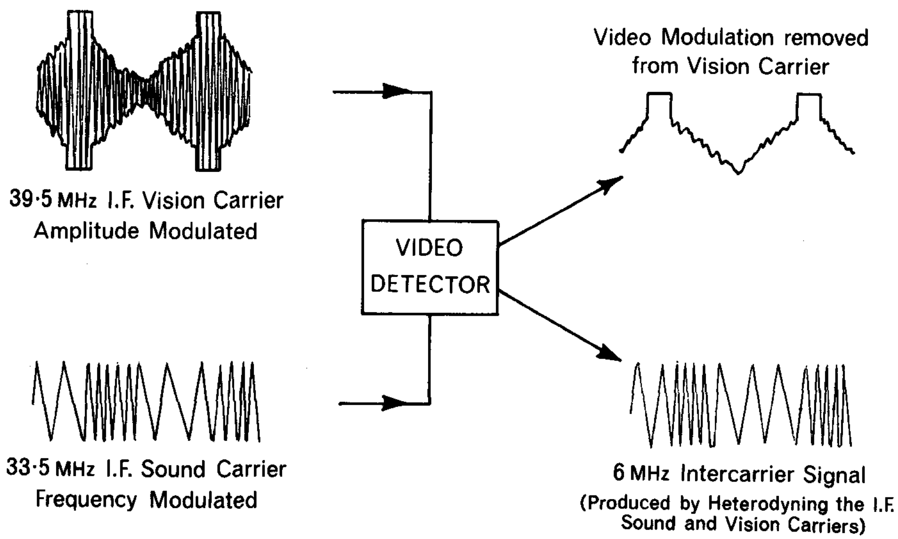
The basic purpose of the video detector is to remove the video modulation from the vision i.f. carrier so that it may be used (*a*) to modulate the raster on the picture tube, and (*b*) to synchronise the operation of the line and field scanning generators. You will recall that the video signal contains all the detail of the picture signal produced by the camera, plus the synchronising and blanking pulses required to trigger the scanning circuits of the receiver.

In many ways, the function of the video detector is similar to that of the sound detector whose job, you will remember, was to remove the sound signal modulation from the sound i.f. carrier so that it could be used to operate the loudspeaker. Indeed, since both these detectors have in common a demodulating role, they are often referred to as *sound and vision demodulators.*

When the Dual-Standard receiver is switched to "405" and is therefore receiving on VHF, its sound and vision circuits are, as you know, separated before they reach the detection stage, and demodulation is all the video detector has to do. On "625", however, where the intercarrier method is used, the video detector is also required to accept both the sound and vision i.f. carriers, and to produce from them a 6 MHz difference, or beat-frequency, signal for input to the separate sound detector. The two essential tasks of the video detector in an intercarrier type of receiver are therefore:

1. **To remove the video signal modulation from the vision i.f. carrier.**
2. **To produce the 6 MHz beat signal from the sound and vision i.f. carrier.**

You will now see how these requirements are met.



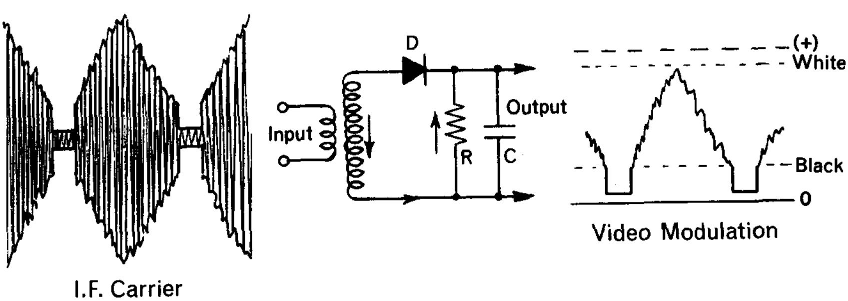
THE FUNCTION OF THE *VIDEO DETECTOR*

The Video Detector—Basic Circuit

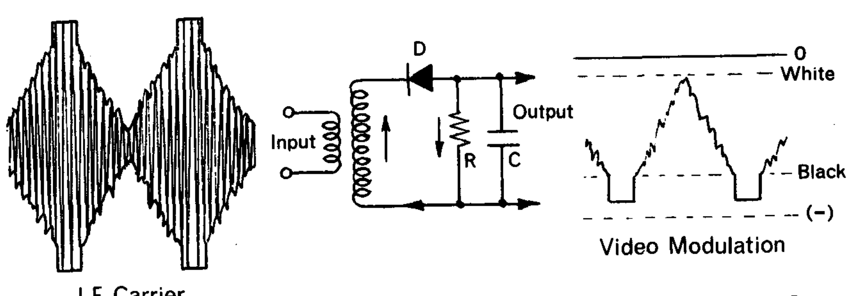
You know that both the i.f. vision carriers (VHF and UHF) are amplitude-modulated by the video signal, which means that the video detector circuit must respond to changes in signal amplitude. This is achieved by using a simple half-wave diode rectifier circuit which differs little from the detector circuit in an ordinary AM radio receiver—the main difference between the two lying only in the frequency of the modulating signals.

In the 405-line TV system, the polarity of the video modulation is positive, so that the amplitude of the vision carrier becomes greater as the whiteness of the camera scene is increased. The converse is true of the 625-line system, in which carrier amplitude is *decreased* as the scene is made whiter. A video detector designed to operate on a positively modulated signal needs to have its diode connections reversed if it is to provide a rectified output signal of the correct polarity after being supplied with a negatively modulated signal. Receivers designed for dual standard operation achieve this by having the diode connections electrically reversed when the *Standard Selection* control is switched from "405" to "625".

The diagrams below show, in a simplified way, how the video modulation is removed from carriers having opposite modulation polarities. The arrows indicate the direction of current flow in the circuit during the half-cycles when the diode *D* is *conducting*. The rectified output signal (*i.e.*, the video modulation) is the mean voltage developed across the load resistor *R* from the pulses of current charging the load capacitor *C* during these conducting half-cycles.



***POSITIVE* Demodulation (405-Line System)**



***NEGATIVE* Demodulation (625-Line System)**

The Video Detector—Frequency Response

There are several reasons why the simple detector circuits you have just looked at are unsuitable in their present form—one of the principal ones being their inadequate frequency response.

You will recall from what you learnt in Part I that the frequency content of the video signal ranges from zero (= d.c.) up to about 5·5 MHz (the width of the unsuppressed sideband of the UHF vision carrier). This frequency spectrum contains not only the variations of the picture signal itself, but also the unvarying repetition frequencies of the line and field blanking and synchronising pulses. It is of the first importance that the shape of these pulses—especially the sharp leading edges of the sync pulses—should be preserved, for otherwise the synchronisation of the line and field scanning pulses will become erratic and the picture reproduced on the screen (particularly of the larger sizes of picture tube) will become unacceptably ragged.

These sharp edges of the sync pulses introduce into the video signal a comparatively high-frequency component which, though not as important numerically as the high-frequency component of the video signal itself, is a good deal more important operationally and must at all costs be preserved. Since the rise-and-fall times of the sync pulses are of the order of 0·25 μs (corresponding to a maximum harmonic frequency of 1 MHz), the video detector must have a frequency response of at least that value if it is to be able to reproduce the sync pulses without distortion.

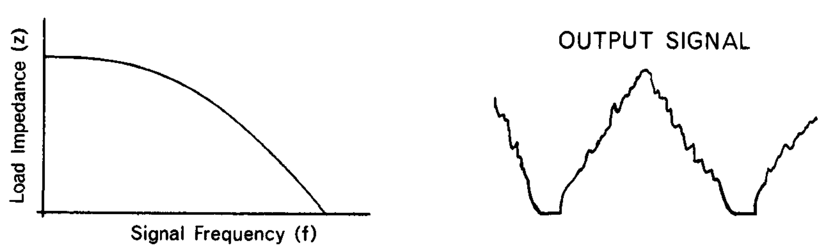
The simple detector circuits on the last page in fact have a poor frequency response. This is because the load impedance (Z) formed by the combination of R and C is sharply reduced as signal frequency rises. You learnt in *Basic Electricity*, Part 4, that the impedance of an RC combination is given by the equation

$$Z = \frac{R \times X_c}{\sqrt{R^2 + X_c^2}}$$

where X_c is the capacitive reactance, which can be quantified as $X_c = 1/2\pi fC$.

Work out the elementary algebra of the equation, and you will see that at very low signal frequencies the value of X_c is high and the load is mostly resistive. A good signal can therefore be developed across the large R. But as signal frequency rises, the value of X_c drops to a low value, the load becomes mainly capacitive, and signal development is poor.

At HIGH Signal Frequencies, Frequency Response is POOR



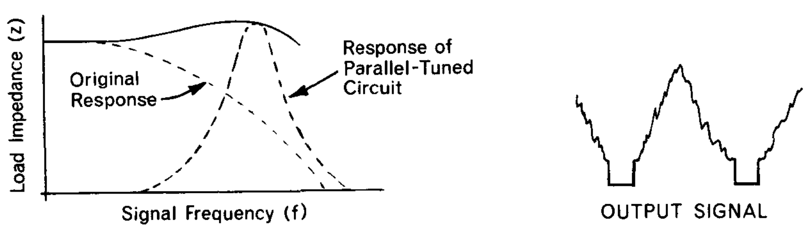
One solution to the problem which is theoretically possible would be to make the value of R so small that any variations in the value of X_c would become insignificant. But a very low value of R would result in an unacceptably small output signal, and some other remedy must be sought.

The Video Detector—Frequency Response (*continued*)

A more hopeful solution is to add something to the circuit which automatically increases the value of the load as the value of X_c falls. The obvious answer is some sort of inductance, since the reactance of an inductor (as you know) increases as the frequency rises ($X_L = 2\pi fL$). So a parallel tuned circuit is formed from a coil and its stray capacitances, and is connected in series with the load.

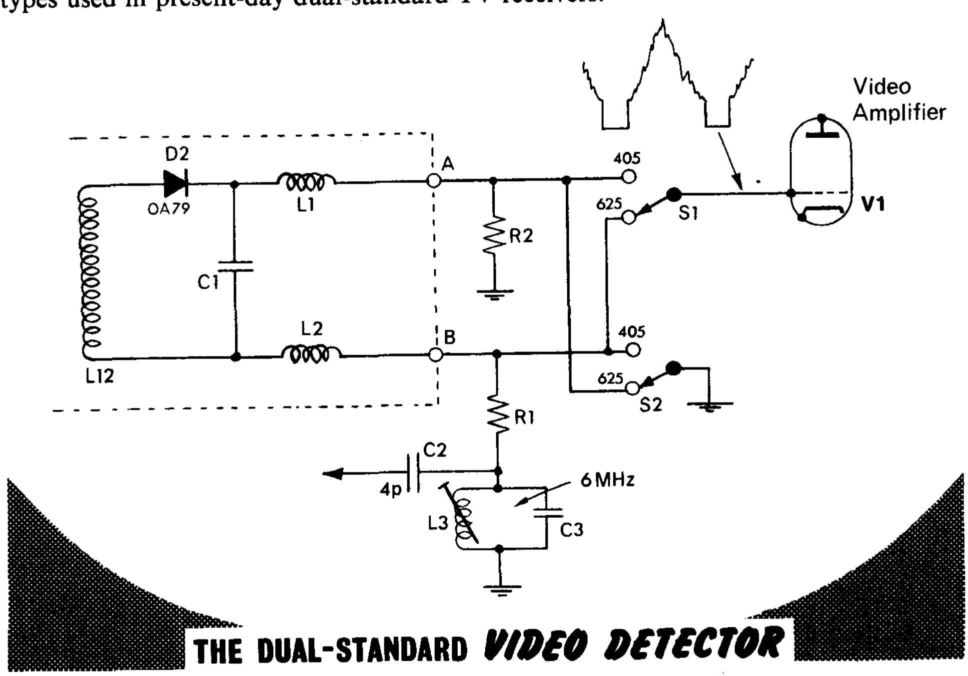
Now, as signal frequency rises, so the impedance of the parallel circuit increases and compensates for the reduction in X_c. In other words, the "droop" in the frequency response curve shown in the illustration on the last page is "jacked up" by the parallel circuit, and the all-important leading edges of the sync pulses are kept sharply defined.

At HIGH Signal Frequencies, Frequency Response is now IMPROVED



The Video Detector Circuit on a Practical Dual-Standard Receiver

The illustration below shows a video detector circuit representative of the many types used in present-day dual-standard TV receivers.



The Video Detector Circuit on a Dual-Standard Receiver *(continued)*

The detector is the semiconductor diode D1, which receives its input signal from the tertiary winding L12 on the second i.f. transformer in the anode circuit of the second i.f. amplifier valve—V2 in the illustration on page 2.99. It is common practice to house this diode, its filter capacitor C1 and the frequency compensating components L1–L2 within the screening can of the i.f. transformer itself—as indicated by the light dotted lines surrounding these components in the illustration on the last page. The function of the filter capacitor and of the inductors L1 and L2 is to ensure that the frequency response of the detector does not extend much above 6 MHz. To the i.f. frequencies much higher than 6 MHz which are encountered on both line standards the circuit acts as a very low shunt impedance—thereby preventing these frequencies from reaching the Video Amplifier.

The two output terminals of the detector circuit, labelled A and B in the illustration, are taken to two sections (S1 and S2) of the *Standard Selection* switch. The circuit arrangement is such that the signal fed to the Video Amplifier is *always positive-going*, irrespective of the polarity of the signal modulation.

When the switches are set to "405", terminal B, and with it the negative electrode of the diode, is taken to earth through S2. Terminal A, and with it the positive electrode of the diode, is taken to the resistor R2 which forms the detector load. The video modulation from the 405-line i.f. carrier is developed across this load, and taken via S1 as a positive-going signal to the grid of the Video Amplifier valve V1. You will see that this form of connection resembles the theoretical circuit shown in the top half of the illustration on page 2.117.

When the switches are set to "625", the video modulation is taken from the negative electrode of the diode, so achieving the same result as if the connections to the diode were physically reversed when the *Standard Selection* switch is turned. Terminal A and the positive electrode of the diode is now taken to earth through S2. Terminal B and the negative electrode is taken to the resistor R1, which is connected in series with a 6 MHz parallel-tuned circuit formed by L3 and C3. This combination R1–L3–C3 forms the detector load across which the video modulation of the 625-line i.f. carrier is developed and taken (again as a positive-going signal) through S1 to the grid of the Video Amplifier valve. This form of connection can be compared with the theoretical circuit shown in the lower half of the illustration on page 2.117.

The 6 MHz tuned circuit L3–C3 offers a very high impedance to signals of that frequency. There will therefore be strongly developed across it the 6 MHz intercarrier signal produced by the beating together (heterodyning) of the sound and vision carriers (39·5 and 33·5 MHz respectively). The intercarrier signal is taken through the capacitor C2 to IF Amplifier B, where you have already seen how its audio modulation is removed.

To signals whose frequencies are significantly different from 6 MHz, the impedance of the tuned circuit L3–C3 is very low; and this low impedance, forming a potential divider circuit with R1, ensures that negligible signal voltages other than the wanted intercarrier signal are developed across it and fed to IF Amplifier B.

Note especially in the illustration the ways in which the 405-line and the 625-line detector loads are shorted to earth, both through S2, when the *Standard Selection* switch is set to "625" and "405" respectively. This arrangement ensures that only wanted signals are applied to the Video Amplifier, and (on the 625-line standard) only the wanted 6 MHz intercarrier signal is sent on its way to IF Amplifier B.

The Video Detector Circuit on a Dual Standard Receiver *(continued)*

One further point. Since the 625-line sound and vision i.f. carriers are made to beat together to produce a 6 MHz beat-frequency intercarrier signal, why (you may ask) is not a 3·5 MHz beat-frequency signal produced from the heterodyning of the 405-line sound and vision i.f. carriers? The answer is, of course, that the 405-line sound i.f. carrier does not pass through IF Amplifier A at all, and that numerous precautions in the way of tuned rejector circuits are taken in IF Amplifier A to keep it out.

Despite these precautions, however, it is still possible for *some* sound i.f. signal to reach the video detector, particularly in strong signal areas; and where this happens, a 3·5 MHz beat-frequency signal is in fact produced. If this were allowed to reach the Video Amplifier, it would appear on the picture tube as a pattern of interference in the form of dots.

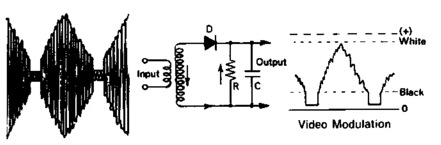
To eliminate this danger, some video detector circuits incorporate a 3·5 MHz rejector circuit connected in series with the output; but a more usual method is to connect a parallel-tuned rejector circuit of 3·5 MHz frequency in series with the cathode lead of the Video Amplifier valve. This you will see in the next Section.

REVIEW of the Video Detector Circuit

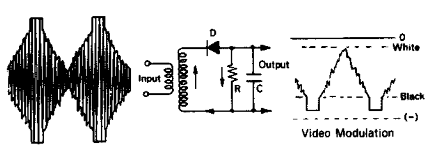
The function of the Video Detector is to remove the video-signal modulation from the i.f. vision carrier, and to apply it to the video amplifier. In both 405-line and 625-line systems, the vision carrier is *amplitude-modulated* by the video signal.

The British Dual-Standard receiver, when it is switched to 625 lines, also requires the video detector to produce a 6 MHz *intercarrier* signal from the heterodyning of the sound and vision carriers, whose frequencies differ by this amount. This intercarrier signal has impressed on it the frequency modulation of the *sound signal,* which it takes to the sound detector in another part of the receiver.

The Video Detector usually consists of a single semiconductor diode whose connections can be electrically reversed so that it can be used on both the VHF (405-line) and UHF (625-line) standards.



POSITIVE **Demodulation (405-Line System)**



NEGATIVE **Demodulation (625-Line System)**

§15: THE VIDEO AMPLIFIER

The video signal has now been separated from the vision carrier, but its amplitude is still far below that required to modulate the picture tube and so build up the picture on the screen. The actual amplitude of the signal at the video detector will depend partly on the strength of the received signal and partly on the degree of overall amplification given by the IF Amplifier; but it is seldom more than a volt or two, whereas some picture tubes require a modulating signal of as much as 70 V to produce a peak-white picture.

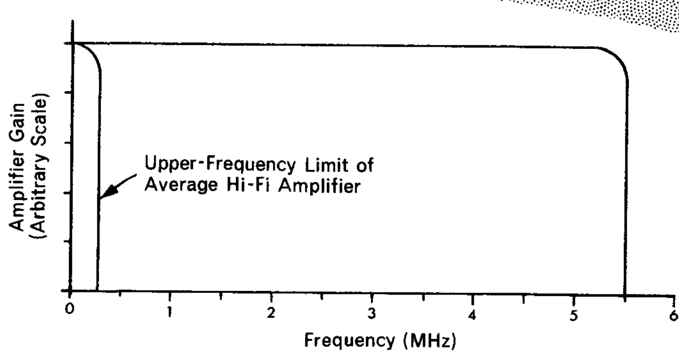
Clearly, then, considerable amplification is required, which it is the job of the video amplifier to provide.

One of the difficulties in the design of a video amplifierfor a Dual-Standard Receiver arises from the need to maintain unimpaired the shape of the video signal over the extremely wide frequency band-width of the signal (3·5 MHz in the 405-line system and 5·5 MHz in the 625-line system). Unless this shape is preserved right up to the point at which it is applied to the picture tube, the quality of the reproduced picture will suffer and its synchronisation will be impaired.

Another requirement the video detector must fulfil is that the d.c. level produced by the video detector (*i.e.*, the average value of the video signal) should also be passed by the amplifier and amplified along with the video signal. This d.c. level, as you know, represents the average brightness level of the scene (its background illumination). It must therefore be applied to the picture tube along with picture-signal content of the video signal if the true tonal composition of the scene is to be preserved.

Since a d.c. level represents a frequency of zero Hz, the frequency response demanded of the video amplifier should ideally extend from zero up to 5·5 MHz (625-line system).

Ideal Frequency Response of the VA
OF A DUAL-STANDARD RECEIVER



As any hi-fi enthusiast will tell you, this is a formidable frequency response to ask for—much greater than that demanded of the most expensive amplifier used for the reproduction of music, which seldom exceeds 100 kHz and is usually much less.

The Video Amplifier (*continued*)

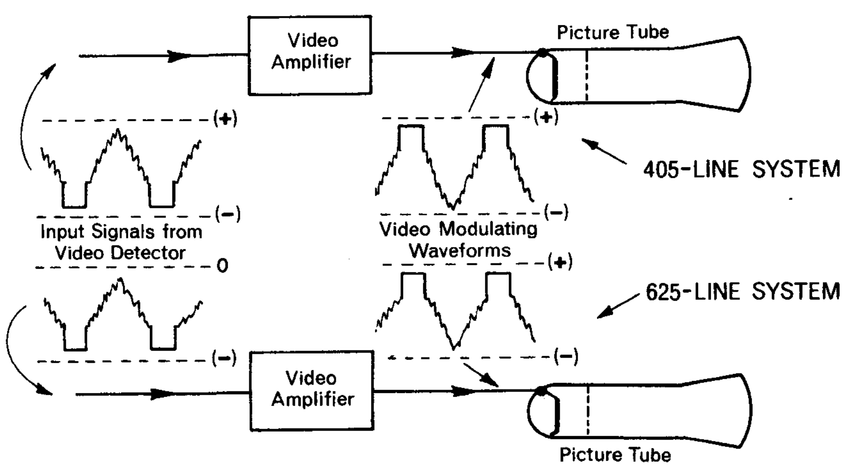
Most modern TV receivers employ a single stage for the video amplification. This automatically introduces one inversion (180°) of the video signal—whereas, of course, a two-stage amplifier would introduce two inversions of the signal (360°) and so produce an output signal of the same polarity as the input.

It is usual to feed the amplified, and inverted, video signal to the *cathode* of the picture tube—which means that maximum brilliance of the reproduced image will occur when the amplitude of the video signal is at its *minimum* value. (A reduction in voltage on the cathode of the picture tube produces the same effect as does an increase in the voltage on the control grid, the intensity of the electron beam being thereby increased.)

It would, of course, be perfectly possible to reverse the connections to the video detector diode (and therefore the polarity of the separated video signal) and to feed the inverted output signal from the video amplifier to the *grid* of the picture tube, instead of to its cathode. This method, known as *grid modulation*, is seldom used, however, since under certain operating conditions, particularly when switching *ON* and *OFF*, it is possible to cause damage to the picture tube by excessive beam current, and extra circuit components are necessary to prevent this happening.

Since the 405- and 625-line systems employ opposite modulation polarities, the video detector diodes in the two circuits are, as you know, connected in opposite directions. The video signals fed to the video amplifiers are therefore of the same relative polarities in both systems. Thus peak-white level in the video signal produced by the 625-line system detector is represented by the maximum positive-going excursion of the waveform above the sync level (even though the whole of the waveform lies below zero volts); while in the 405-line system detector, peak-white is represented by the maximum positive excursion of the waveform *above* the zero-volt level.

After inversion by the video amplifier, however, peak-white is represented in both systems by the *minimum* excursion of the video signal, which thus produces maximum scanning beam intensity and maximum brilliance of the picture.



MODULATING the PICTURE TUBE

Frequency Compensation

The video amplifier itself usually consists of a single pentode valve having a resistive anode load (R_L). Within limits, the larger the value of this load, the greater will be the overall gain (A) of the stage. To put it mathematically, $A = G_m \times R_L$, where G_m is the mutual conductance of the valve expressed in mA/V.

In practice, however (as was also true of the video detector), the actual value of the anode load is not just R_L, but rather the combination of R_L and the reactance of sundry stray capacitances in parallel with it. These stray capacitances are the output capacitance of the valve itself, plus the capacitances existing between individual wires and components, and plus the input capacitance of the picture tube and of the sync separator stage.

If, correctly, the load is now expressed as an impedance Z_L, the gain of the pentode becomes $A = G_m \times Z_L$, with

$$Z_L = \frac{R_L \times X_c}{\sqrt{R_L^2 + X_c^2}}$$

where X_c (the reactance of the stray capacity in parallel with R_L) $= 1/2\pi fC$.

You will see that the magnitude of Z_L depends on the value of X_c, which in turn is inversely proportional to the frequency of the signal. It follows that Z_L, and therefore A, will decrease as the frequency rises. The extent of the variation in Z_L depends, of course, on the value of the stray capacity, which is typically of the order of 25 pf.

Take a simple example. Assume a value of 10 k for R_L, and say the frequency of the applied signal is as low as 50 Hz. The value of X_c at this frequency is $1/(2 \times 3{\cdot}14 \times 50 \times 25 \times 10^{-12})$, or about 130 megohms. The effect of 130 M in parallel with 10 k is, of course, negligible and the presence of X_C may therefore be ignored. At this frequency, then, the value of Z_L is effectively R_L, and $A = G_m \times 10^4$.

But consider what happens when the frequency of the applied signal is increased to 5 MHz—as it very well may be in the 625-line system. The value of X_C is now only $1/(2 \times 3{\cdot}14 \times 5 \times 10^6 \times 25 \times 10^{-12})$, or about 1,300 ohms—some 10,000 times less than it was at 50 Hz. With the value of X_c now comparable with that of R_L, it becomes important in determining the value of Z_L. The equation is now:

$$Z_L = \frac{10{,}000 \times 1{,}300}{\sqrt{10{,}000^2 + 1{,}300^2}} \doteqdot 130 \text{ ohms},$$

so that $A = G_m \times 130$.

With the value of the anode load impedance varying from 10,000 ohms at 50 Hz to 130 ohms at 5 MHz (a gain change of nearly 80 : 1), some form of frequency compensation is clearly required to stabilize the value of the anode load as the frequency alters.

Alternatively, the value of R_L can be made so small compared with the lowest value of X_c that the effect of changes in X_c become insignificant. In practice, both methods are employed. R_L is commonly reduced to a value equal to about twice the value of X_c at the highest frequency in the bandwidth, and inductive compensation is achieved by placing a small inductor in series with R_L.

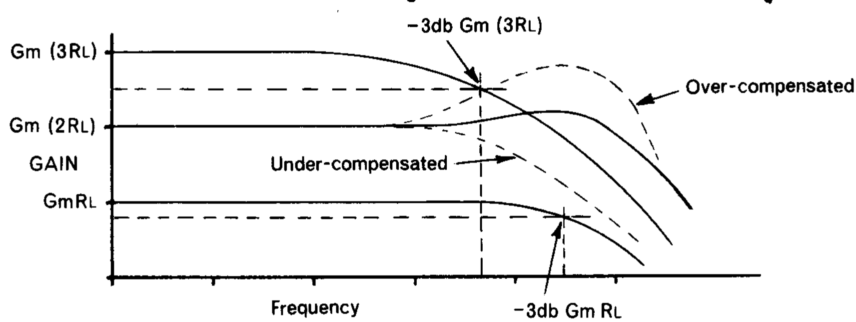
Frequency Compensation (*continued*)

Various arrangements have been tried for stabilising the frequency response of the video amplifier by means of an inductor coil connected as part of the effective load (Z_L) of the valve. Some receivers employ two coils connected in a series/shunt arrangement, while others favour a single coil with a cathode-follower feed to the picture tube. The simplest arrangement, however, consists of a single coil connected in series with the anode load (R_L), the presence of this coil being enough to cause the effective value of R_L to increase with frequency and so compensate for the reduction in Z_L caused as X_c falls. (You will recall that a similar arrangement was used to boost the frequency response of the cascode amplifier in the tuner stage. The coil was there referred to as a "peaking coil", and the same name is given to the coil used in the video amplifier.) The value of the inductance of the peaking coil is carefully chosen so that it will form a parallel resonant circuit with the stray capacitances of the circuit at a frequency *slightly higher* than the maximum frequency it is desired to handle.

A further advantage of the peaking coil is that the presence of R_L in series with it introduces considerable damping of the tuned circuit, and so makes its frequency response broader.

The illustration below shows three frequency response curves—G_mR_L, $G_m(2R_L)$ and $G_m(3R_L)$—in which the value of the anode resistance is progressively doubled and then trebled, but in only one of which, $G_m(2R_L)$, is a compensating peaking coil used. (Note that it is customary, when assessing the effective bandwidth of an amplifier, to cite *the frequency at which the gain of the amplifier has fallen by a specified amount.* This amount is usually (−)3 dB, at which the gain is 70% of maximum.)

How FREQUENCY COMPENSATION *Improves* GAIN



Other things being equal, the gain of an amplifier, as you know, becomes greater the larger the value of its R_L. G_mR_L, therefore, though its frequency response shows comparatively little drop at the (−)3 dB point, gives only poor gain. $G_m(3R_L)$, equally uncompensated, shows excellent gain—but one which drops off so sharply as frequency rises that the crucial (−)3 dB point is reached with a considerably smaller frequency excursion.

Note, by contrast, the effect which a peaking coil of the proper value has on the $G_m(2R_L)$ curve, permitting the use of a load resistor of twice the uncompensated value yet with a frequency response at least as good.

The two dotted lines in the illustration show the results of connecting a peaking coil of the wrong value. Typically, such coils are not physically larger than is a quarter-watt resistor. They have inductance values of between 100 and 200 microhenries.

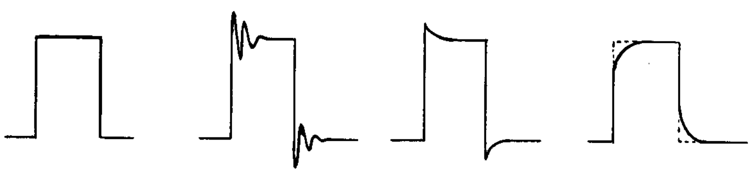
Ringing and Overshoot

If the current flowing in a peaking coil (or in any other tuned circuit for that matter) is suddenly cut off, the energy stored in the capacitor and coil at the time of cut-off will cause the circuit to oscillate for a few cycles before it settles down to the zero-current condition. This phenomenon is known as "ringing". The same thing happens when current is suddenly *applied* to a tuned circuit, the circuit going through a short oscillatory phase before settling down.

In some applications (radar and oscilloscope calibration circuits are examples) the ringing of a tuned circuit may be of value. In the TV video amplifier, it is most undesirable. This is because it causes what is known as "overshoot" on the video signal waveform fed to the picture tube, and this causes a peculiar shimmering effect on the edges of the component parts of the picture appearing on the screen. What happens is that normally white areas of the picture are very rapidly succeeded by identically-shaped black areas, and then by more white areas. A similar alternation of white and black areas follow each original black area which appears.

Overshoot can also affect synchronising efficiency, particularly of the line timebase circuit, causing the timebase to be prematurely triggered and so giving parts of the picture ragged edges.

Ringing can be controlled to an acceptable degree by connecting a resistance of carefully chosen value in parallel with the peaking coil. Controlling the ringing of a tuned circuit in this way is known as "damping". The choice of a damping resistor of the correct value is crucial. The illustration shows what will happen if a mistake is made.



Ideal Waveform

Undamped Waveform Bad Overshoot and Too-high Frequency Response

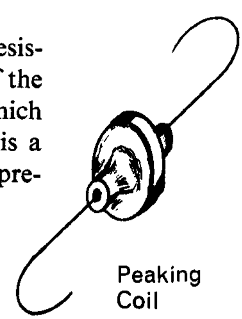
Correct Damping Negligible Overshoot

Excessive Damping No Overshoot but Impaired Frequency Response

THE EFFECTS OF *Damping* ON A STEEP-SIDED WAVEFORM

Thus under-damping leads to overshoot, and excessive damping reduces the frequency response of the peaking coil—which defeats the whole object of putting the coil there in the first place.

It is common practice to wind a peaking coil over the top of a resistor whose value is just right to stop the coil ringing. The ends of the coil are connected to the leads of the resistor, the body of which serves as a support, or "former", for the coil. The outcome is a compact and easily-handled peaking circuit which is already precisely damped before use.



Biasing Levels in the Video Amplifier

If the video amplifier is to produce a faithful amplification of the video signal applied to its grid, the grid bias voltage must be so adjusted that the full amplitude of the signal coming from the video detector can be accommodated within the grid base of the valve. In other words, the extremities of the grid waveform must not extend beyond the cut-off and grid-current limits of the grid base. (This sort of requirement, of course, applies to any amplifying system in which fidelity of reproduction is important and is in no way peculiar to the VA.)

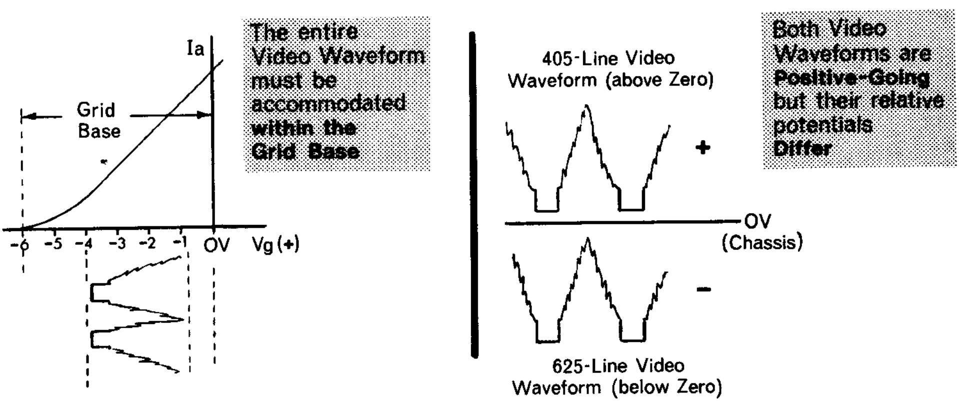
If the signal applied to the video amplifier grid were symmetrical in shape, having equal positive and negative areas like a sine wave, it would be sufficient to set the grid bias level in the centre of the linear region of the grid base. The positive and negative excursions of the input signal would then extend by equal amounts above and below the grid bias value, and the whole of any signal of normal amplitude would be contained within the grid base.

But the shape of the video signal waveform is *not* symmetrical; and its mean value, or d.c. level, being representative of the mean brightness level of the transmitted scene, can never be predicted. In some cases, the picture signal may not even be present at all in the video signal, even though the sync pulses are there—as sometimes happens just before the start of a programme when a blank screen appears on the picture tube.

All video waveforms are basically unidirectional in nature, *i.e.*, their polarity referred to zero is either wholly positive or wholly negative. Bias voltage levels for the video amplifier must therefore be referred to this zero voltage reference, and not to some arbitrary level which may not always be present.

You know that, on both the 405 and the 625-line systems, the signal coming from the video detector is of positive-going polarity, but that the relative potentials of the two waveforms are different. In the video waveform of the 405-line system the sync level is only slightly above chassis potential, the complete waveform being *positive* with respect to chassis. In the 625-line system, the near-zero condition of the video waveform is that corresponding to peak white, the complete waveform being *negative* with respect to chassis. It is because of these differences that a video amplifier designed to operate from a 405-line video waveform needs a different bias level from one required to operate from a 625-line signal.

In the British Dual Standard Receiver, the grid bias level of the video amplifier is one of the many things which are changed when the *Standard Selection* switch is moved from one of its positions to the other.

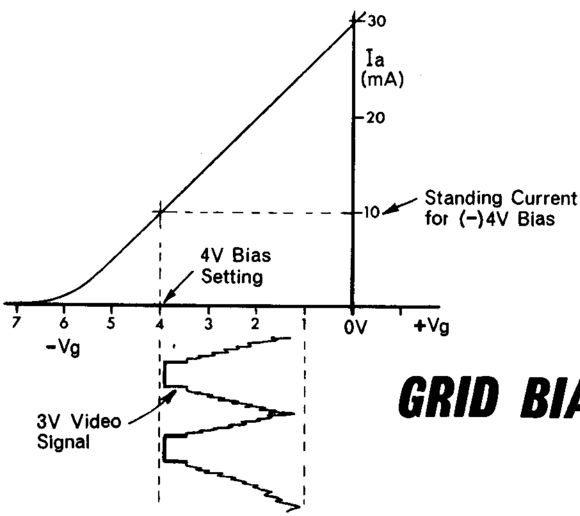


Biasing for the 405-line System

The lowest value of the 405-line video waveform is that which corresponds to sync level, which is slightly above chassis potential. The remainder of the waveform—black level and picture-signal content—all represent increases above this level. To handle this type of signal, the grid bias voltage of a video amplifier should be set to a level sufficiently negative to ensure adequate grid base accommodation for the full positive excursions.

Consider, for instance, a video signal waveform having a maximum overall amplitude of 3 volts, and a sync level corresponding to zero potential. To accommodate such a signal at its grid, the grid bias of the VA must be set to a level of at least (−)3 V. The video signal will then "sit" on this value of bias, and all its positive excursions will just be accommodated within the grid base of the valve, the most positive excursions of the video signal just reaching the zero voltage region of the I_a/V_g curve.

But if, as is the case in the illustration below, the grid base of the valve is considerably more than 3 V, then a larger value of negative bias is possible. A grid bias of (−)4 V, for example, would not only ensure that the positive peaks of the video signal were well clear of the zero-volt region (the point at which grid current starts to flow in the valve and introduces distortion of the signal), but would also reduce the standing current in the valve. (This standing current is the value of anode current which flows in the absence of a video signal. In the case shown, it is 10 mA.)



GRID BIAS for the 405-LINE VIDEO SIGNAL

It is important that the biasing point be kept well clear of the curved portion of the I_a/V_g curve that lies in the region approaching I_a cut-off. If the tips of the sync pulses extend into this region, amplification of the pulses will be very nonlinear. Distortion of the sync pulses and consequent impairment of synchronising efficiency will result.

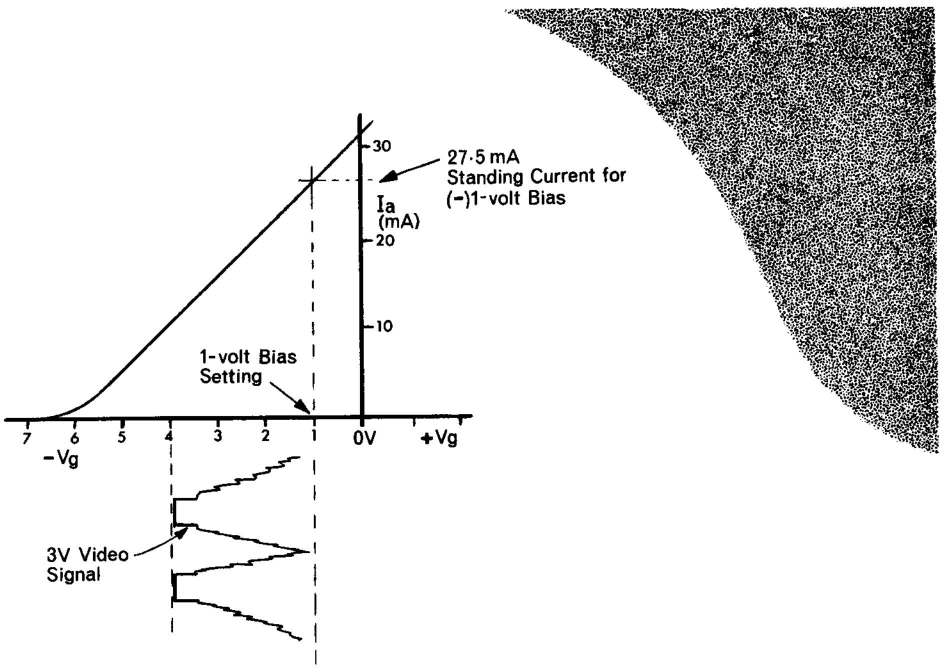
So the bias level should be set to a value which (*a*) ensures that the full amplitude of the video signal is embraced by the linear portion of the I_a/V_g curve, and (*b*) maintains the lowest possible standing anode current.

Biasing for the 625-line System

In the 625-line system, the polarity of the video waveform coming from the video detector circuit is entirely negative with respect to chassis, and maximum negative amplitude occurs at the tips of the sync pulses (*i.e.*, at sync level). The minimum level reached by the signal is that representing peak white, which is slightly below zero.

For the VA to be able to handle the 625-line video signal, its bias level must be fairly close to the zero V_g point of the valve so that the full negative excursions of the signal can be accommodated within the grid base. Consider, for example, a video signal of 3 V amplitude reaching the grid of a pentode having a grid base of about 6 V. A bias level of about (−)1 V would be required to accommodate the 3 V excursions of the signal, which would extend from (−)1 V to (−)4 V.

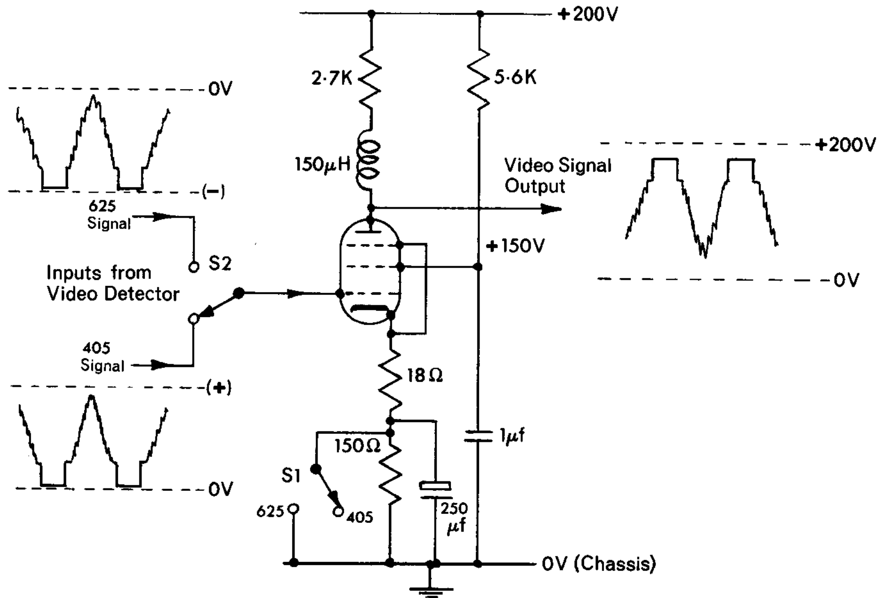
In the absence of a video signal, the standing current corresponding to a (−)1 V bias level would be about 27·5 mA. This is considerably higher than was the standing current in the 405-line system, and is a disadvantage of this type of circuit.



GRID BIAS for the 625-LINE VIDEO SIGNAL

The Dual-Standard Video Amplifier

It follows from what you have just read that an essential part of an adequate video amplifier for a Dual-Standard receiver is some mechanism for changing the bias conditions on the cathode of the amplifying pentode when the *Standard Selection* switch is rotated from "405" to "625", or *vice versa.* The illustration below shows one way in which this is done.



The Basic Circuit of the DUAL-STANDARD *Video Amplifier*

The pentode is powered from a 200 V HT supply and has a 2·7 k anode load frequency-compensated by a 150-microhenry peaking coil. Screen grid voltage is derived from the 200 V supply through a 5·6 k resistor, producing a screen grid voltage of about 150 V. The 5·6 k resistor is decoupled by a 1-mfd capacitor.

The cathode circuit of the valve contains two resistors connected in series. One of these is quite small in value (only 18 ohms); the other, comparatively large (150 ohms), has a 250 mfd decoupling capacitor connected in parallel with it. These two components form a conventional cathode bias circuit. One section of the *Standard Selection* switch (S1) is connected across this cathode bias circuit in such a way that in one of its two positions it "shorts" the whole of the circuit to earth.

When S1 (and with it, of course, S2) is set to accept the positive-going 405-line video signal, S1 is open-circuited and the cathode bias components are able to develop the large negative bias required. The value of the 150-ohm bias resistor is carefully chosen so that the bias voltage developed across it sets the operating point of the valve well down in the negative region of the I_a/V_g curve—but also well clear of the point at which the curve really *begins* to curve near I_a cut-off. With components of the values shown, the bias voltage developed is about 3·5 V, which means that the grid circuit of the valve can accommodate a maximum video signal amplitude of about that value.

The Dual-Standard Video Amplifier (*continued*)

When S1 is set to accept the negative-going 625-line video signal, the two cathode bias components are short-circuited to chassis, leaving only the 18-ohm resistor in series with the valve. With such a small value of resistance in the cathode circuit, only a small bias voltage (about 0·6 V) will be developed across it; and the operating point of the valve on the I_a/V_g will be close to the point where V_g is zero.

This is, as you know, the required operating point for the "625" signal. The illustration opposite also shows that a bias setting of about 0·6 V will allow the grid circuit of the valve to accommodate a maximum video signal amplitude of about 3·5 V, as it did for the 405-line signal.

There are three reasons for the presence in the circuit of the 18-ohm resistor. First, it serves to protect the valve from the excessively high standing current which would result if grid voltage were reduced completely to zero. It does this by virtue of the small bias voltage which it develops across itself.

Second, this small bias voltage ensures that the signal peaks corresponding to the highlights of the picture do not extend into the positive grid-voltage region of the I_a/V_g curve. If this were allowed to happen, grid current would flow at these moments; and a heavy load would be placed on the video detector which would cause distortion of the video signal and of the picture appearing on the picture tube.

Lastly, by careful choice of the value of this resistor and by omitting to put into circuit with it any decoupling capacitor, negative feedback is introduced and the gain of the valve for both 405-line and 625-line signals can be made the same. This reduces the need for adjustment of the *Contrast Control* every time a different standard is selected.

Some TV receivers avoid the need for changing the video amplifier bias whenever the line standard is changed by employing a.c. coupling between the video detector and the grid circuit of the VA. In this arrangement, a steady Class A bias voltage is developed by the cathode bias components, and the video signals from either standard swing about their average values within the linear region of the I_a/V_g characteristic.

The penalty to be paid is, of course, that the d.c. component of both signals is lost, and must be put back in again at a later stage by the technique of d.c. restoration.

Another disadvantage of a.c. coupling is the sudden, momentary changes which occur in the operating point of the valve whenever the mean brightness level of the studio scene changes abruptly. This is caused by the flow of current in the coupling capacitor as it charges to the level required of it on the new standard. The changes in operating point introduced in this way are often large enough to cause distortion of the video signal, either because grid current momentarily starts to flow or because part of the signal momentarily extends into the curved portion of the characteristic.

Distortion of this nature can be avoided, at the expense of reduced amplification, by restricting the amplitude of the video signal applied to the VA to about 70% of what could otherwise be accommodated.

Reducing Beat-Frequency Interference in the Dual-Standard Video Amplifier

A somewhat more elaborate arrangement is adopted in the cathode circuit of some Dual-Standard VA's, with the object of further reducing the ever-present danger of signal distortion arising from the unwanted presence in the amplified video signal of the beat-frequency signals of the respective i.f. carriers on both standards. In this arrangement, a tuned rejector circuit is connected in series with the cathode lead components in the circuit shown in the last illustration.

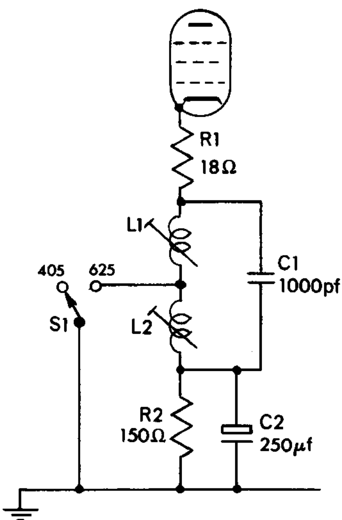
In the circuit below, the two resistors now marked R1 and R2, and the capacitor now marked C2, function exactly as they did before, and S1 acts on them in the same way. But S1 is now arranged to act also on a section of the rejector circuit L1–L2–C1 so that this circuit can perform two specific tasks.

When the switch is set to the "405" position, the rejector circuit functions as a parallel-tuned circuit resonant at 3·5 MHz, the total inductance being the sum of the series-connected inductors L1 and L2. In other words, $(L1 + L2)C1 = 3{\cdot}5$ MHz. When connected in this way, the rejector offers a very high impedance to the difference frequency of the 405-line sound and vision i.f. carriers (3·5 MHz) and causes the cathode bias of the valve to be extremely high to signals of this frequency. Thus the valve offers very little amplification to such signals, and they are prevented from reaching the picture tube with any magnitude.

When the switch is set to the "625" position, the inductor L2 is shorted to earth, and the rejector tuned circuit is formed by L1 and C1 only. With the inductance reduced in this way, the circuit has a higher resonant frequency—and this frequency is arranged to be 6 MHz, the frequency of the 625-line intercarrier frequency.

A rejector circuit of this type thus causes the valve to give almost no amplification to either the 405- or the 625-line i.f. carrier beat-frequency signals, and thereby reduces the likelihood of these signals distorting the picture.

REDUCING
BEAT-FREQUENCY INTERFERENCE
in the
DUAL-STANDARD VIDEO AMPLIFIER



You could put the above explanation more shortly by saying that, on 405 lines, L1–L2–C1 form a 3·5 MHz trap for the 405-line i.f. carrier; while on 625 lines, L1–C1 form a 6 MHz trap for the 625-line intercarrier signal.

Contrast Control

One other item of circuitry is normally located in the video amplifier stage of the Dual-Standard Receiver. It is the *contrast control,* which is usually situated physically somewhere between the circuitry of the VA and that of the picture tube. The contrast control itself needs always to be operated in conjunction with the *brightness control,* which you will be learning about in the next Section.

Contrast is a term used in TV to describe the ratio of the illumination of the brightest to that of the darkest parts of the reproduced image on the picture tube. A picture having excessive contrast is composed of unnaturally black and excessively white areas, with few intermediate half-tones. Dark grey suits appear jet black, and ordinary pale faces snowy white. At the other extreme, all the constituent parts of a picture having poor contrast appear in almost the same greyish half-tone, with few contrasting dark and bright areas. A pale face now, whatever its owner's state of health or emotion, looks just about the same colour as does the dark grey suit he is wearing in the studio. . . .

The contrast of a TV picture is determined by the *difference of amplitude between the two extreme levels* of the picture-signal content of the video waveform applied to the picture tube—the levels representing black and white. The further these are apart, the greater will be the contrast; the closer they are together, the poorer will be the contrast. Regulating the contrast of the reproduced picture is therefore only a matter of devising a control which allows the amplitude of the video signal fed to the picture tube to be adjusted by the viewer to what he considers gives the best results.

The *brightness control,* which can also be operated by the viewer, allows him to adjust the *overall background brightness* of the picture. It should normally be set to reproduce as closely as possible the mean illumination level of the studio scene. Since the contrasting dark and bright areas of the picture must all be referred to (or compared with) this steady background brightness level, it follows that the contrast and brightness controls are mutually related and need to be adjusted in conjunction with one another to produce the best results.

There are several ways in which the amplitude of the video signal applied to the picture tube can be controlled. Three possible ones are shown overleaf.

In (**A**), the amplitude of the video signal from the VA is controlled by varying the amplitude of the un-amplified signal applied to the grid of the pentode. This is called *low-level contrast control,* and is performed by varying the setting of the potentiometer RV1.

In (**B**), the amplitude of the video signal produced by the VA is controlled by varying the gain of the amplifier itself. This is done by varying the screen-grid potential with the aid of the potentiometer RV1.

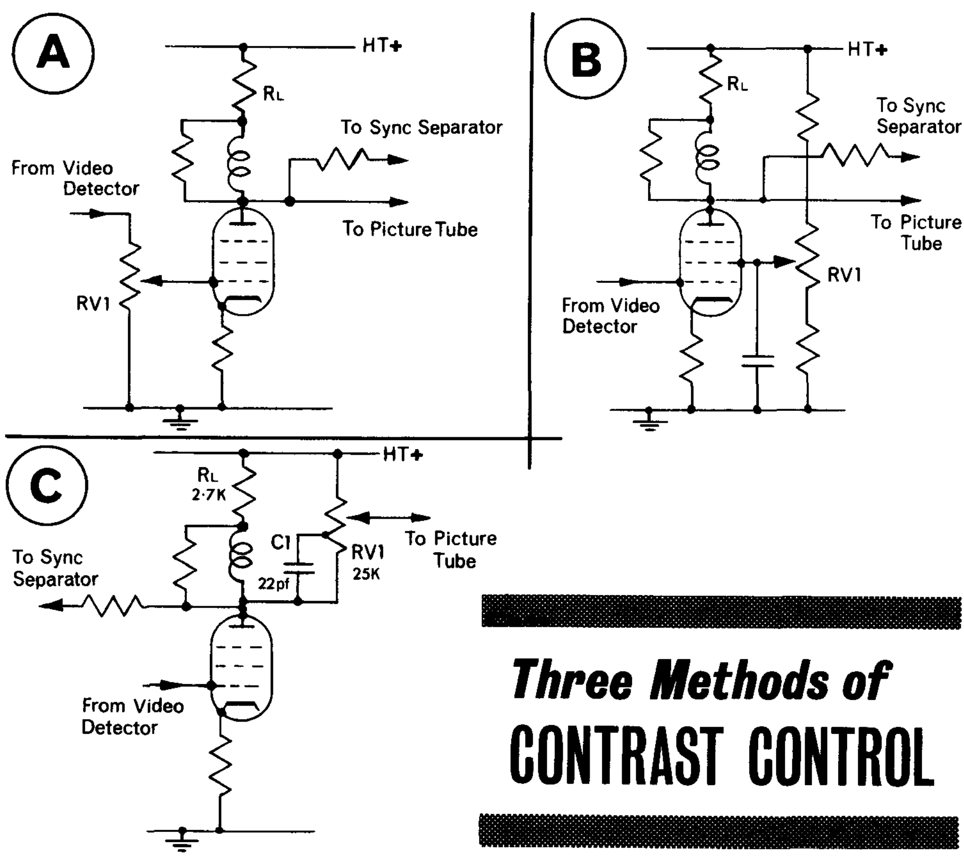
In (**C**), the amplitude of the signal applied to the VA and the gain of the VA itself are both unaffected by the operation of the *contrast control* knob. Instead, the full amplitude of the amplified video signal is developed not only across the anode load of the VA, but also across a large-value potentiometer connected in parallel with it. The value of this potentiometer (again *RV1* in the illustration overleaf) is nearly ten times the value of the anode load resistor R_L. The object is to keep its power dissipation as low as possible. The variable contact of the potentiometer is connected directly to the picture tube, and enables the amplitude of the video signal applied to the tube to be varied simply by adjustment of the control. This method is known as *high-level contrast control* and is the type used in most Dual-Standard TV receivers.

Contrast Control (*continued*)

The principal disadvantage of Circuits **A** and **B** below is that in both of them the amplitude of the signal applied to the sync separator circuit is affected. Variations in the amplitude of the sync pulses contained in this signal can easily upset the synchronisation of the receiver. In Circuit **C** (given adequate signal strength at the aerial) the amplitude of the signal applied to the sync separator circuit is not affected by adjustments to the *contrast control*, and the amplitude of the sync pulses can be maintained at a constant level by the AGC circuit which controls the gain of the preceding i.f. stages.

One danger in Circuit **C** needs to be guarded against. The connection of a comparatively bulky component like a variable resistor in parallel with the anode load of the VA can increase the stray capacitances existing at that point. In practice, these effects of added capacitance are kept to a minimum by physically positioning the potentiometer *RV1* as close as possible to the anode circuit of the valve (using a long operating shaft extending to the front or side of the receiver).

In addition, further frequency compensation is provided by the small-value capacitor C1 connected across part of the potentiometer control. Without this capacitor, some of the higher-frequency components of the video signal would be lost by reason of the extra stray capacitances; and unequal attenuation of the video signal would result when the control was adjusted.



Three Methods of

CONTRAST CONTROL

REVIEW of the Video Amplifier

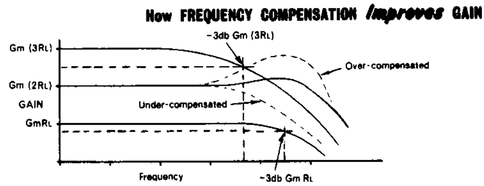
The job of the video amplifier is to impart to the video signals coming from the video detector on both line standards an amplification of the order of 35 to 50 times, while at the same time maintaining unimpaired the shape of the video signals over the whole of their wide frequency bandwidth (3·5 MHz on the 405-line standard and 5·5 MHz on the 625-line standard).

Most TV receivers employ a single stage for video amplification, so automatically introducing a 180° inversion of the signal. On both standards, the video signal is *positive-going*, though in the 405-line system the whole of the signal lies *above* chassis potential, while in the 625-line system it lies *below* it.

Peak white is.represented, in the 405-line system, by the maximum positive excursion of the waveform above chassis potential; while in the 625-line system it is represented by the maximum positive excursion of the waveform above sync level.

Frequency compensation, needed to stabilise the value of the anode load of the amplifying pentode when the picture-signal frequency increases, is achieved partly by limiting the value of the anode load (and thereby the gain of the valve), and partly by connecting a small peaking coil in series with R_L. The result aimed at is a frequency response curve of the general shape of the curve of $G_m(2R_L)$ in the illustration below.

How FREQUENCY COMPENSATION *Improves* GAIN



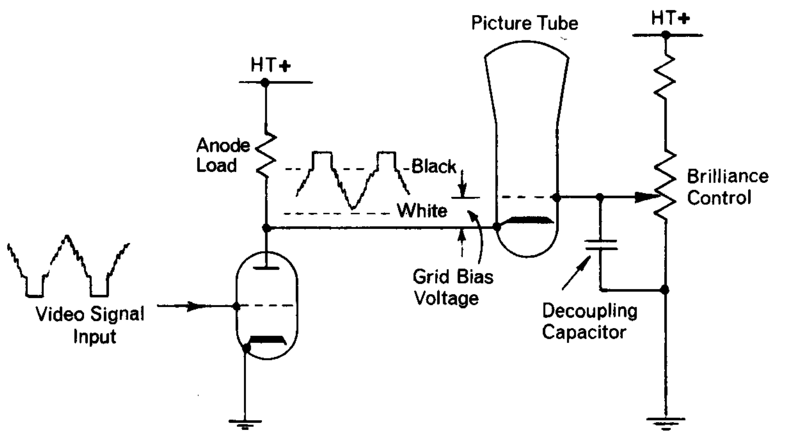
Grid biasing is required in the pentode of the video amplifier in order to keep the voltage on its grid sufficiently negative to provide adequate grid-base accommodation for the full positive-going excursions of the video signal on both standards.

The *Contrast Control* enables the viewer to adjust to his liking the ratio between the brightest and the darkest parts of the reproduced image on the picture tube. The control is operated in conjunction with the *Brightness Control*, whose circuit is situated in the picture tube stage.

§16: COUPLING THE VIDEO SIGNAL TO THE PICTURE TUBE

The signal leaving the video amplifier is of sufficient amplitude and of the correct polarity to modulate the electron beam of the picture tube, and so to build up on the screen the picture transmitted from the studio. The basic connecting circuits are shown in the illustration below (from which the *contrast control* circuitry, which you already know about, has been omitted for the sake of clarity).

Note that the connection shown, again for simplicity, is a d.c. one. In practice, you will see that there are objections to this, and that something rather more complex is normally used instead.



How the *Video Signal* is taken to the *Picture Tube*

The picture tube itself is nothing more than a specialized form of display-type cathode-ray tube (CRT), about which you learnt all you need to know at this stage in the last dozen pages of *Basic Electronics*, Part 5. The actual screen is a coating of fluorescent material on the inside face of the tube.

The electron stream, constantly modulated in intensity by the variations of the video signal, is made to travel very fast indeed over the face of the screen in a series of interlaced lines one below the other. The deflections of the beam from left to right, and from one line to another below it, are caused by varying the currents flowing in the line and field deflection coils, respectively, of the CRT—the whole process being performed so fast that the fluorescent glow excited on the screen by the passage of the electron beam is renewed before the viewer's eye has had time to note any sign of fading.

Modulating The Picture Tube

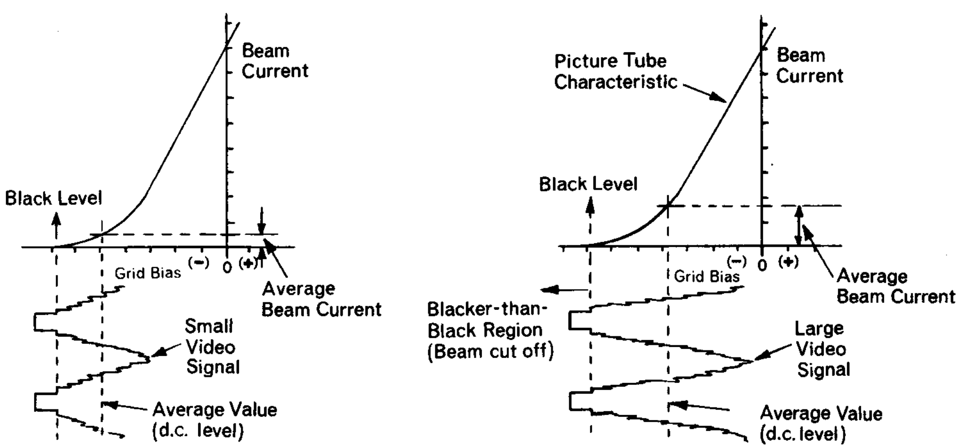
In a modern TV receiver, the video signal is usually applied to the *cathode* of the picture tube, and its polarity is negative with respect to its grid. In other words, the highlights of the scene are represented by the *most negative* excursions of the waveform. The grid is maintained at a constant potential selected by the *brilliance control* (of which more later), and is decoupled by a large-value capacitor so that it is effectively at earth potential with regard to the variations of the video signal.

With the cathode made negative with respect to the constant potential on the grid, the beam current is affected just as it would be if the grid were made positive with respect to a constant-potential cathode. In either case, the brilliance of the picture appearing on the screen will be greatest when the cathode is most negative.

The illustration opposite shows in principle how the video signal is connected to the cathode of the picture tube from the anode of the video amplifier. With such a connection, the cathode is normally maintained at a positive voltage equal to the steady anode potential of the VA, but will faithfully follow the variations in potential which occur across it. When there is no picture-signal content in the video signal (sync pulses and blanking pulses only), the VA anode will be at a relatively high positive potential because, with the average value of the video signal low, little anode current flows and there is only a small voltage drop across the anode load.

Under these conditions, the bias on the picture tube (the difference between its grid and cathode voltages) is highly negative. It is at this point, as you will see in a moment, that the viewer should adjust the *brilliance control* so that the raster on the screen becomes *just invisible.*

Now when a picture signal appears at the anode of the VA, the cathode potential of the picture tube rises and falls in sympathy with the variations of the picture signal and the density of the electron beam is modulated accordingly. The greater the amplitude of the picture signal, the greater the voltage drop across the VA anode load and the lower the anode voltage. The resulting much-less-positive potential on the cathode of the picture tube reduces the negative grid bias of the tube and increases the brilliance of the picture on the screen.



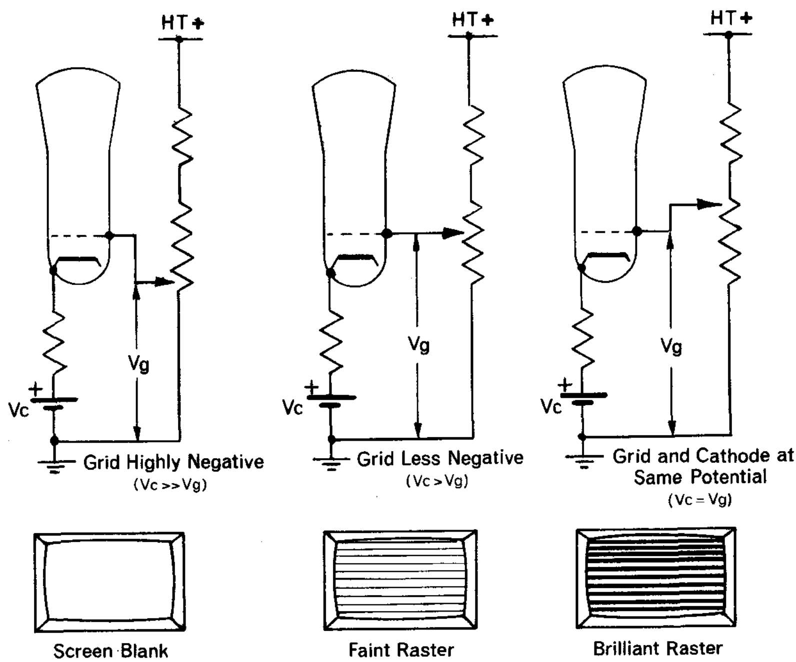
When GRID BIAS is *Reduced* PICTURE BRILLIANCE *Increases*

Brilliance Control

You know that the *average value* (d.c. level) of the video signal represents the average illumination level of the studio scene, and that the average brightness of the picture produced on the screen is determined by the average value of the grid bias of the picture tube. This bias can be controlled by the viewer by manipulation of the *Brilliance Control* knob on the outside of his receiver set.

The *brilliance control* circuitry is quite simple, consisting essentially of a potentiometer connected between HT (+) and earth, with its movable slider connected to the grid of the picture tube. With the grid made *highly negative* ($V_c \gg V_g$—see illustration below), the beam is cut off. With the grid *less negative*, a faint raster appears on the screen. With *both grid and cathode at the same potential* ($V_c = V_g$ and grid bias is zero), beam current is much increased and the raster on the screen shows up brilliantly.

How the *Brilliance Control* Affects the *Raster*



Normally, *brilliance control* should be adjusted until the unmodulated raster is made just invisible. This setting corresponds to the black level of the video signal. As soon as picture-signal content is added to the latter, VA anode voltage drops, the cathode of the picture tube becomes less positive, the intensity of the scanning beam is increased above that corresponding to black (invisible) level, and a picture appears on the screen with a tonal value according well with that of the studio scene.

The D.C. Component of the Picture Signal

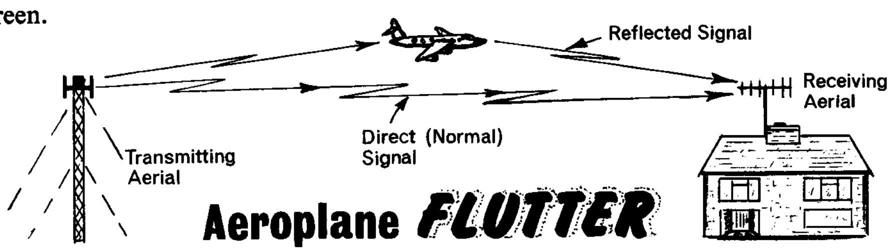
You have just seen the importance of the d.c. component of the video signal in controlling the overall brightness of the scene traced out by the electron beam on the face of the picture tube, and you will have noticed the straightforward d.c. connection used to couple the video signal to the cathode of the picture tube in the illustration on page 2.136. Such a connection is essential for coupling a d.c. signal to a subsequent stage; for if a capacitor is used instead, the d.c. content of the video signal will be blocked, only the a.c. content of the signal will reach the tube, and the picture on the screen will appear most unnatural.

Yet, for all the value of the job it does, there are good technical reasons why the size of the d.c. component of the signal should be at least reduced. One of these reasons, put forward by some TV receiver manufacturers, is the fact that large changes in the illumination of a studio scene will give rise to correspondingly large changes in the beam current in the picture tube. These changes impose large load variations on the EHT supply to the picture tube; and unless this supply is stabilised in some way, it will tend to vary with every change in beam current. This would be most undesirable, for variations in EHT affect the deflection sensitivity of the tube and hence the size of the picture presented. (A voltage supply which behaves in this way is said to have *poor regulation.*)

But EHT stabilising circuits capable of producing good regulation are expensive, so some manufacturers prefer (despite its disadvantages) an a.c. type of coupling between the video amplifier and the picture tube. With this type of coupling, no d.c. component can reach the cathode of the picture tube, and no automatic variation can take place in the level of the bias on its grid.

Another disadvantage of d.c. coupling is the accentuation it gives to the type of interference known as "aeroplane flutter" which you met briefly earlier on. When an aeroplane is flying close to the receiver and to the line-of-sight path between receiver and transmitter, the body of the aeroplane will reflect some of the signal from the transmitter and the receiver will pick this signal up along with the signal it receives by the normal direct route. If the two signals happen to arrive in phase, they combine to produce an abnormally strong signal which causes a sudden increase in the amplitude of the video signal fed to the picture tube. The result, of course, is an increase in the contrast of the picture appearing on the screen.

But since the aeroplane is moving, the distance between it and the receiver is constantly changing. So the phase of the reflected signal at the receiver relative to the normal signal will progressively change, and will at some time be in complete anti-phase to the normal signal. It will therefore subtract from it instead of adding to it. There will be a decrease in combined signal strength, a corresponding decrease in the amplitude of the video signal—and therefore in the contrast of the picture on the screen.

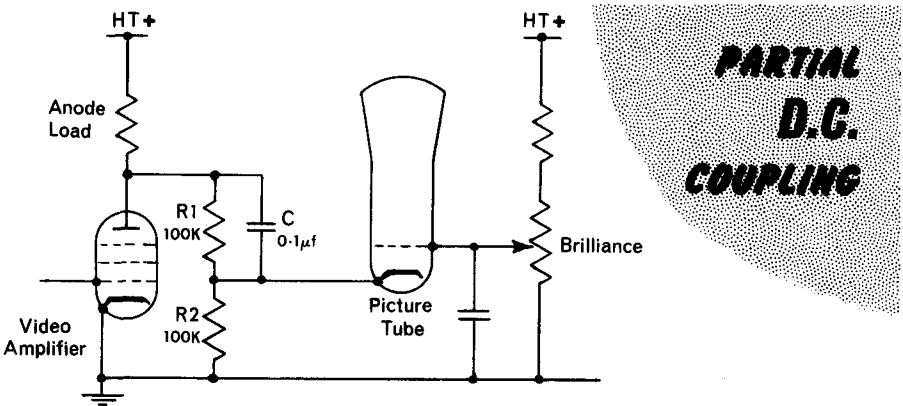


The D.C. Component of the Picture Signal (*continued*)

As the aeroplane continues to move nearer and nearer to the receiver, the maximum-to-minimum variations in the received signal continue to occur quite smoothly, but the time difference between them becomes progressively shorter until the eye fails to detect the rapid changes in contrast. This usually occurs at about 20–30 variations per second, at a time when the noise of the aeroplane itself can be heard by the viewer.

Two principal methods are used for coupling the video signal to the picture tube in such a way that the advantages of d.c. coupling are retained while its disadvantages are minimized. The first is a technique called *partial d.c. coupling*. The second is to use a.c. coupling, but to *restore* a d.c. component to the video signal after coupling has been achieved.

The illustration below shows a typical circuit providing partial d.c. coupling between the VA and the picture tube.



The video signal at the anode of the VA is developed across two series-connected 100-kilohm resistors (R1, R2), the upper one of which is shunted by a 0·1 mfd capacitor. The cathode of the picture tube is connected to the junction between the two resistors. To the d.c. component of the video signal the capacitor C behaves like an open-circuit; so the amplitude of the d.c. level is reduced by one-half before it is applied to the picture tube. (Since R_1 and R_2 are of equal value, half the level will be developed across each.)

To the higher-frequency a.c. components of the video signal, however, the capacitor offers a very low reactance ($X_c = 1/2\pi fc$), which effectively short-circuits R_1. Signals of such frequencies are therefore developed across R_2 only, and are applied to the picture tube with no attenuation. But since the reactance of the capacitor varies inversely with frequency, its reactance to the lower-frequency components of the video signal is much greater than it is to the higher-frequency ones. As the reactance of the capacitor becomes greater, so its shunting effect on the parallel-connected resistor (R_1) becomes less, and the attenuating effect of the two resistors becomes greater.

The D.C. Component of the Picture Signal (*continued*)

Take, first, a high-frequency a.c. component of 100 kHz. The reactance of the capacitor at this frequency is:

$$X_c = \frac{1}{2\pi fc} = \frac{1}{6{\cdot}28 \times 10^5 \times 0{\cdot}1 \times 10^{-6}} = \frac{100}{6{\cdot}28} \simeq 16 \text{ ohms.}$$

A reactance of this value is so small compared with the 100 k resistor R_1 with which it is connected in parallel that almost all the signal will be developed across R_2 and practically none across R_1. The signal will therefore be applied to the picture tube without attenuation.

But consider a very low-frequency a.c. component like that produced by aeroplane flutter—say, 10 Hz. The reactance of the capacitor at 10 Hz is 10,000 times greater than it was at 100 kHz, and is therefore about 160 k. A reactance of this value is comparable to the value of R_1 itself (100 k) and must therefore sharply raise its effective resistance. Indeed, the effective resistance of the parallel combination of C and R_1 now becomes

$$\frac{R_1 \times X_c}{R_1 + X_c} = \frac{100 \times 160}{100 + 160} = \frac{16{,}000}{260} = 61{\cdot}5 \text{ kilohms.}$$

The signal amplitude actually applied to the picture tube (*i.e.*, that which is developed across R_2 at varying values of the frequency of the a.c. component of the video signal) can be worked out by means of a formula. Let V volts be the value of the a.c. component of the video signal, and R' be the value of the effective combination R_1 and the reactance of C. Then $V = R_2/(R' + R_2) \times V$.

In the case of a low-frequency a.c. component like that produced by aeroplane flutter, and using the figures calculated above, $V = 100/(61{\cdot}5 + 100) \times V = 0{\cdot}62$ volts.

So with V reduced by a factor of 0·62 before it is applied to the picture tube, the interference caused by aeroplane flutter will be reduced by a similar ratio.

When purely a.c. coupling is used to couple the video signal to the picture tube, the lost d.c. component can be reinstated by the circuit technique of *d.c. restoration.* For economic reasons, the technique is seldom employed nowadays in TV receivers, but you may sometimes find it in receivers of earlier design in which grid modulation was employed.

An alternative technique is called *d.c. clamping.* It is similar in operation to d.c. restoration, but requires a continuous source of operating pulses called *keying* or *clamping* pulses.

Put shortly, the differences between the two techniques are as follows:

The **d.c. restorer** circuit operates on the *most positive* (or, alternatively, on the *most negative*) excursion of the video signal waveform in any given period, and restores this level to a predetermined potential.

The **d.c. clamping** circuit operates on *any selected part* of the video signal waveform and restores this level to a predetermined potential. The circuit is more versatile than the d.c. restorer, but more complex. For this reason, clamping circuits are generally confined to TV transmitting equipment, and are seldom used in receivers.

THE SERIES CONTINUES

The story of the British Dual-Standard receiver is now continued in Part 3 of this Series on *Basic Television*, beginning with an account of how the synchronising pulses are separated from the picture-signal content of the video waveform, and then how the field sync pulses used to enable the field scan generator to produce an accurate vertical scan of the picture tube are separated from the line sync pulses used to enable the line scan generator to produce an accurate horizontal scan of the tube.

INDEX TO PART 2

Acceptance Angle 2.44
Acceptance Bandwidth 2.25, 2.39 *et seq.*
Aerials 2.4, 2.17 *et seq.*
Aeroplane Flutter 2.139
AGC Blocking 2.102
Audio Amplifier 2.114
Automatic Gain Control (AGC) 2.9

Bandpass Filter 2.51, 2.97
Bat-wing Aerial 2.40
Beat-frequency Interference (in VA) 2.132
Bias levels in VA 2.127 *et seq.*
Bottom Capacitance Coupling 2.79
Brilliance Control 2.138

Cascode Amplifier 2.61 *et seq.*
Channel Selection (in VHF Tuner) 2.66 *et seq.*
Clamping Pulses 2.141
Conical Dipole Aerial 2.40
Contrast Control (in VA) 2.133 *et seq.*
— — Knob 2.9
Corner Reflectors 2.38
Critical Coupling (of tuned circuits) 2.97
Cross-Modulation 2.101

Damping 2.96
D.C. Clamping 2.141
— component of Picture Signal 2.139
— Restoration (in some types of VA) 2.131, 2.141
De-emphasis Filter 2.114
Delta Matching (of feeder cable to aerial) 2.35, 2.47
Diplexer 2.49 *et seq.*
Dipole Aerials 2.19 *et seq.*
— Length 2.23 *et seq.*
Directors 2.28 *et seq.*
Double Yagi, with Skeleton Slot 2.35

End-fed Dipole 2.48

Feeder Cables, from Aerial 2.46 *et seq.*
Field Scan Section of Receiver 2.11
Flutter, Aerial 2.27
—, Aeroplane 2.139
Folded Dipole 2.30
— Slot Aerial 2.34
Forward Gain (of aerial array) 2.28
Frame Grid Valves 2.64 *et seq.*
Frequency Changers (VHF) 2.68 *et seq.*
— — (UHF) 2.78 *et seq.*
— Compensation (in VA) 2.124
— Discriminator 2.104
— Response, of Aerial 2.25 *et seq.*
— — in IF Amplifier 2.92 *et seq.*
— — in Tuner 2.80 *et seq.*
— — in Video Detector 2.118 *et seq.*

Front-to-Back Ratio 2.27
Full-Wave Dipole Aerial 2.20
Ghosts (TV) 2.33, 2.42 *et seq.*
Grid Modulation (in VA) 2.123
Grounded-Cathode Triode 2.61
Grounded-Grid Triode 2.61

H-Aerial 2.26
Half-Wave Dipole Aerials 2.19 *et seq.*, 2.22 *et seq.*
High-level Contrast Control (in VA) 2.133
Home-made Aerials 2.52 *et seq.*

IF Amplifier 2.6, 2.83 *et seq.*
"IF Amplifier A" 2.83, 2.89 *et seq.*, 2.98 *et seq.*
"IF Amplifier B" 2.83, 2.102 *et seq.*
Incremental Tuning 2.67
Intercarrier Buzz 2.104
— Signal 2.8, 2.102 *et seq.*
Interference Limiter (at VHF) 2.113

Keying Pulses 2.141

Line Scan Section of Receiver 2.12
Loudspeaker 2.115
Low-level Contrast Control (in VA) 2.133

Miller Effect 2.60
Mixer 2.5
Modulating the Picture Tube 2.137
Multi-Element Aerial Arrays 2.29 *et seq.*
Mutual Conductance (G_m) 2.65

Negative Demodulation 2.117
Neutralising Capacitor 2.63

Over-coupled Tuned Circuits 2.97
Overshoot 2.126

Partial D.C. Coupling 2.140
Peaking Coils 2.63, 2.125
Polarisation (of transmitted signals) 2.31
Positive Demodulation 2.117
Power Gain of Aerials 2.27
Power-Supply Section of Receiver 2.13

Radiation Acceptance Pattern 2.26
R.F. Amplifier Stage of Tuner 2.5, 2.60
Ratio Detector 2.114
Reflectors 2.26, 2.38
Rejector Circuits 2.84 *et seq.*
Resonant Lines 2.72 *et seq.*
Ringing 2.126

Screening (in UHF Tuner) 2.74
Shaping, of Frequency Response Curves 2.96 *et seq.*
Signal Power Distribution 2.92 *et seq.*

Signal Strength Meter 2.41
Signal-to-Noise Ratio 2.44
Skeleton Slot Aerials 2.35
Skin Effect 2.74
Slot Aerials 2.31 *et seq.*
Slotted Cylinder Transmitting Aerial 2.36
Sound Section of Receiver 2.9 *et seq.*
— Signals, Development of 2.110 *et seq.*
Sound-on-Vision 2.89
Stacked Aerial Arrays 2.45
Sync Section of Receiver 2.10 *et seq.*

T-Matching (of feeder cable to aerial) 2.47
Traps 2.84 *et seq.*
Triplexer 2.51
Tuner Stage of Receiver 2.5, 2.59 *et seq.*
Turret Tuning 2.66

UHF Aerials 2.37 *et seq.*
— Triode (in RF Amplifier) 2.76 *et seq.*
— Tuner 2.71 *et seq.*
Undercoupled Tuned Circuits 2.97
Unipole 2.48

Video Amplifier (VA) 2.8, 2.122 *et seq.*
— Detector 2.8, 2.116 *et seq.*
Vision-on-Sound 2.89
VHF Tuner 2.60 *et seq.*

Wire Mesh Reflectors 2.39

Yagi Aerials 2.30 *et seq.*

BASIC TELEVISION

Part 3

A Basic Training Manual developed by

H. A. COLE, C.Eng., M.I.E.R.E.,
working in conjunction with
the Editorial and Art Staff of the Publishers.

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PREFACE

The aim of this Series on *BASIC TELEVISION* is to explain in simple language the physical principles which make television possible and the way in which a typical television system works—from the generation of the signal in the TV camera to the final presentation of the picture on the screen by your own fireside. The Series is based on the two TV systems working in Great Britain today—the very-high frequency (VHF) one working on 405 lines per picture and the ultra-high frequency (UHF) one working on 625 lines per picture. The receiver considered in Parts 2 and 3 is the British Dual-Standard Receiver which is capable, on operation of the "*Standard Selection*" control, of receiving programmes on either of these two considerably different systems.

Two decisions of particular importance had to be made in planning the Series. The first was to describe the working of the TV receiver almost wholly in terms of valves, even though in many of the latest single-standard and colour receivers the thermionic valve is being progressively replaced by semiconductor devices. This decision was made on two grounds. The first was that a large majority of the millions of receivers operational in Britain in the second half of 1971 are wholly or mainly valve-operated rather than transistorized and that, for technical and economic reasons which are more fully discussed in the final Section of Part 3 "TRENDS IN TV RECEIVER DESIGN", the valve will in all probability continue to play an important part in TV receivers, especially in those built on the Dual-Standard principle, for a significant number of years to come. The second reason was that, since the **COMMON-CORE** Series as it exists at present is planned on the basis of explaining the working of electronic devices in terms of current flow through a valve, it was desirable to keep this account of the basic principles on which television works compatible with the foundation **COMMON-CORE** volumes in their present form.

The other major decision in planning *BASIC TELEVISION* was to cover black-and-white ("monochrome") transmission and reception only, in the interest of keeping the descriptions of the various stages in the studio camera, the transmitter and the receiver relatively simple and relatively short. With the basic principles involved thus established (it is hoped) in the reader's mind, a further Series on *Basic Colour TV*, fully transistorized to reflect modern progress, is currently planned.

Most of the measurements given in the Series have been expressed (or in Part 1, which was first published in 1967, re-expressed) in SI Metric units. In particular, "Hertz" and "MHz" have been used in place of "cycles per second" and "Mc/s" throughout. But certain measurements either familiar to the viewer (*e.g.*, the sizes of picture tube) or else representative of orders of magnitude rather than of precise distances have been left in inches, miles, etc., as being more likely in that form to give the ordinary reader a clear picture of the point being made.

The Series has been written and illustrated to take its place in the growing **COMMON-CORE** Series of Illustrated Training Manuals on subjects connected with electricity and electronics. Originated in the United States by the distinguished New York firm of technical education consultants and graphiological engineers,

VAN VALKENBURGH, NOOGER & NEVILLE, INC.

the twenty-one Manuals of which the **COMMON-CORE** Series now consists have already sold over 1,500,000 copies in their British and Commonwealth editions. Six of the Manuals have been wholly conceived, written and illustrated in the United Kingdom; while all the remainder have been extensively rewritten to conform with British terminology and notation.

The *BASIC TELEVISION* Manuals presuppose in the reader a working knowledge of the contents of the foundation volumes of the **COMMON-CORE** Series, principally the five Parts of *BASIC ELECTRICITY* and the six Parts of *BASIC ELECTRONICS*. Prior acquaintance with the two-part series *BASIC ELECTRONIC CIRCUITS* will also prove useful when the operation of the TV receiver is studied in Parts 2 and 3.

The *BASIC TELEVISION* Series has been written, in conjunction with the editorial staff of the Publishers, by **Mr. H. A. Cole**, a Senior Scientific Officer in the Electronics and Applied Physics Division of the Atomic Energy Research Establishment at Harwell. Mr. Cole is a Chartered Engineer, and a Member of the Institution of Electronic and Radio Engineers. All illustrations of a technical nature have been drawn by Mr. Cole himself, with the Art Department of THE TECHNICAL PRESS responsible for their "decoration" and captioning.

TABLE OF CONTENTS

Section		Page
17	Separating the Sync Pulses	3.2
18	The Scanning Generators	3.16
19	Developing the Field Scan	3.40
20	Developing the Line Scan	3.48
21	The Picture Tube	3.66
22	Vision Interference	3.87
23	Automatic Gain Control	3.93
24	Power Supplies	3.112
25	Fault-finding in the TV Receiver	3.117
26	Trends in TV Receiver Design	3.127
	Index to Part 3	3.137
	Cumulative Index to Parts 1–3	3.138

Foreword on International TV Systems

The television set round which this Series has been written is the so-called *British Dual-Standard Set*, which is capable of receiving signals on two distinct line-systems—the 405-line and the British 625-line systems.

If you wonder at the emphasis placed on the word "British" in that phrase, "the *British* 625-line system", the reason for it is that it has regrettably not yet been possible to secure international agreement on all the technical details of any standard 625-line system.

For some time past, it has been the aim of the *C C I R* (*the Comité Consultatif International des Radio*, or *International Radio Consultative Committee*) to persuade all the countries of the world to adopt a common TV system, on the grounds that it would be of great benefit to everyone from the point of view of convenience, ease of programme exchange, and manufacturing economy. Although complete agreement is still a long way off, progress has certainly been made over the past few years.

There are at present seven major TV systems in the world: the American 525-line, the French 625-line, the French 819-line, the West European 625-line, the East European 625-line, the British 405-line, and the British 625-line systems. The British 405-line system is due to be gradually discontinued over the next few years and will eventually be replaced by a 625-line system.

Unfortunately, not all European countries—even the Western ones—agree on the technical details of a standard 625-line system. It is true that they agree on such important features as aspect ratio, scanning sequence, method of interlacing and a few others; but differences still exist over (for example) the choice of vision bandwidth, channel spacing, sound-to-vision carrier spacing, and the degree of modulation which shall correspond to black level. These differences, though not very great, can sometimes prevent satisfactory exchange of two 625-line programmes. For example, the 625-line system employed by Belgium and France uses amplitude modulation for the sound carrier, whereas all other European countries use frequency modulation. Similar differences exist elsewhere in Europe over the relative spacing of the sound and vision carriers.

The Western European and Eastern European systems differ mainly in the values chosen for channel width and vision bandwidth. The Western European system uses a 5 MHz vision bandwidth and 7 MHz channel spacing, whereas the Eastern European system uses a 6 MHz vision bandwidth and 8 MHz channel spacing.

The British 625-line system differs from both European systems in that it uses a 5·5 MHz vision bandwidth and 8 MHz channel spacing. Other differences concern the width of the vestigial sideband and the setting of the black level.

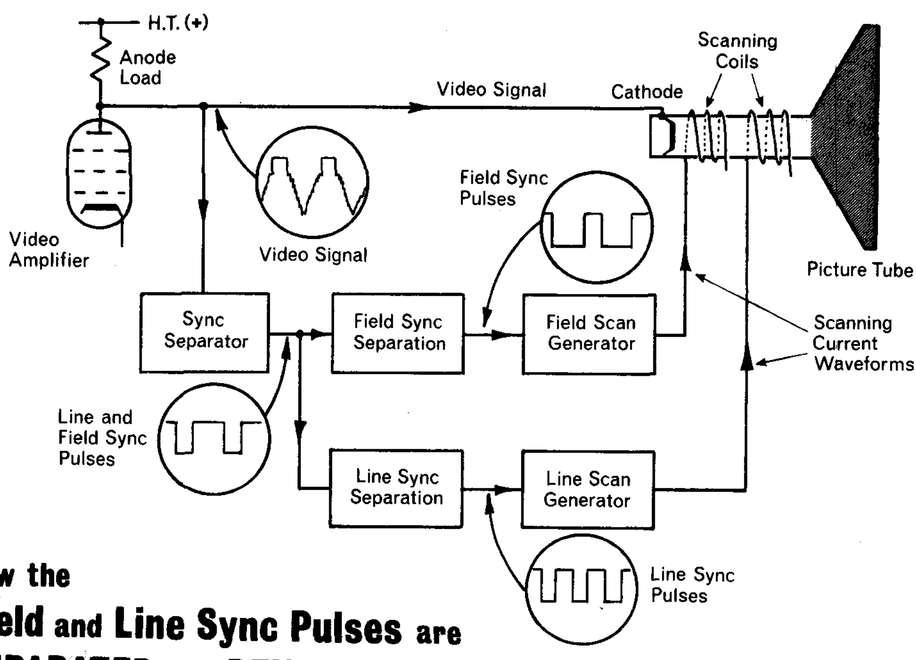
§17: SEPARATING THE SYNC PULSES

The signal leaving the Video Amplifier is of sufficient amplitude and of the correct polarity to modulate the electron beam of the picture tube. But you know from page 1.68 of *Basic Television*, Part 1, that "if the image seen by the viewer is to be a faithful reproduction of that sent out by the studio, it is essential that the scanning spot shall move across the picture tube in the receiver at the same speed and at the same time as the scanning spot moving across the target of the camera tube, and that it shall at all times occupy the same relative position in its scanning field. If any of these conditions are not realised, it will be impossible to keep the picture steady at the receiver; and it may either drift across the screen, dissolve into multiple images, or even break up altogether."

To ensure accurate synchronisation between transmitter and receiver, a series of so-called **sync pulses** were, as you know, mixed with the picture signal in the studio and transmitted with it so as to provide a means of keeping the field and line circuits in the receiver operating exactly in step with similar circuits in the studio camera. You must now see how these sync pulses are separated from the picture-signal content of the video waveform, and then how the field pulses used to enable the field scan generator to produce an accurate vertical scan are separated from the line pulses used to enable the line scan generator to produce an accurate horizontal scan.

Later on, you will see how the separated pulses are developed so as to make them capable of synchronising their respective scanning generators; and how the latter are enabled to produce scanning waveforms accurately synchronised and of suitable shape to be applied to the scanning coils of the picture tube.

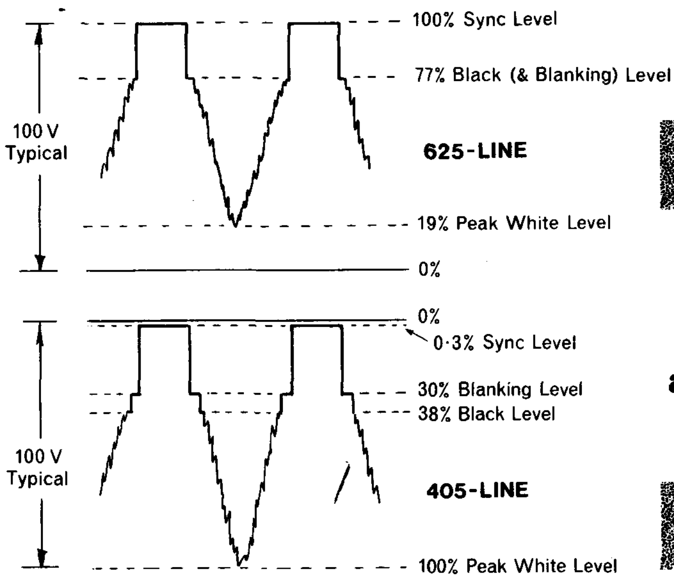
In block diagram form, the process can be followed in the illustration below:



How the Field and Line Sync Pulses are SEPARATED and DEVELOPED

The Sync Separator

Separation of the sync pulses from the video signal takes place in a stage which occurs immediately after the Video Amplifier, known as the **sync separator.** At this stage the video signal is of large amplitude (typically 50–100 V) and, for both 405 and 625-line systems, of negative-going polarity—which means that the picture signal becomes progressively more negative as the brightness of the scene increases. The shapes of the two waveforms are as follows:



The Video Signal Waveforms at the Anode of the Video Amplifier

You can see that on both line standards the sync pulses extend into the blacker-than-black region of the waveforms. In the 625-line waveform, the sync pulses extend from about 77% to 100% of the modulated vision carrier, and the picture signal from about 19% to 77%. Thus, the overall amplitude of the video waveform, expressed as a percentage of the carrier modulation, is $(100-19=)$ 81%. Of this 81%, $(\frac{58}{81}\times 100=)$ 71·6% is occupied by the picture signal, and $(\frac{23}{81}\times 100=)$ 28·4% is occupied by the sync pulses. So with a peak-to-peak video signal amplitude of 100 V, 28·4 V would be represented by the sync pulses and 71·6 V by the picture signal content.

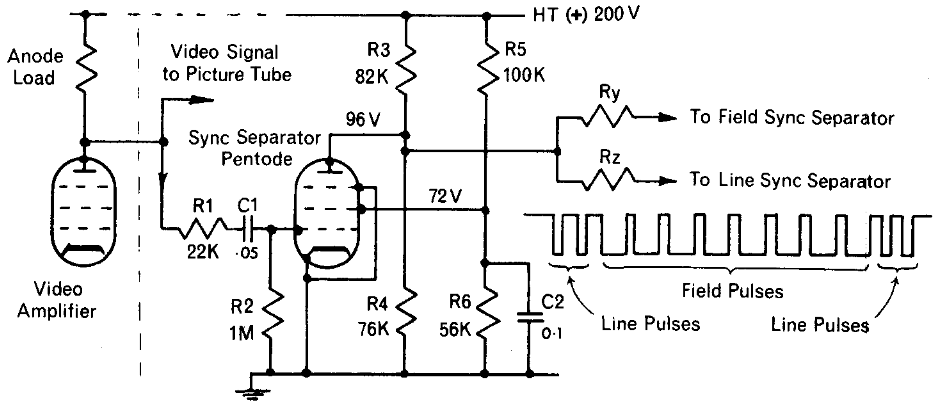
In the 405-line waveform, almost the whole of the vision carrier amplitude is occupied by the video signal modulation; and of this amplitude, 30% is occupied by the sync pulses and $(100-38=)$ 62% by the picture signal. The remaining 8% is occupied by the blanking and black level difference—claimed by the BBC to be nowadays zero but theoretically determined by the contrast range of the camera tube. So with a peak-to-peak video signal amplitude of 100 V, 30 V would be represented by the sync pulses and 70 V by the picture signal-plus-blanking level content.

These proportions are almost the same as for the 625-line waveform, so that the composition of the video signal which the sync separator is required to process is about the same on both line standards.

Since the polarity of the signal is also the same, *no switching is required at the sync separator stage* of the British dual-standard receiver.

The Sync Separator (*continued*)

There are several theoretical ways of separating the sync pulses from the video waveform, but for some years most receivers have employed a simple and efficient method based on a single pentode valve. The circuit of a typical sync separator of this type is shown below:



The SYNC SEPARATOR

The sync separator pentode shown has its cathode connected directly to earth. The control grid is also connected to earth through its grid-leak resistor R_2. The initial bias on the valve is therefore zero.

The negative-going video signal from the anode of the VA is applied to the control grid of the separator through R_1 and C_1. R_1 is used only to isolate the input capacitance and the (low) input impedance of the separator from the anode circuit of the VA: without it, the capacitance would affect the frequency response of the VA and the impedance would damp its anode load. The presence of R_1 also serves to reduce any noise which might be present with the video signal, and which could impair the accurate triggering of the field and line scanning generators.

C_1 and R_2 together give a coupling time constant of long duration which, in coupling the video signal to the separator grid, removes its d.c. level—thereby dividing the signal into equal areas above and below a zero-voltage reference level. This places the sync pulses and part of the picture signal content in the *positive* region of the video waveform, and the major part of the picture signal in the *negative* region.

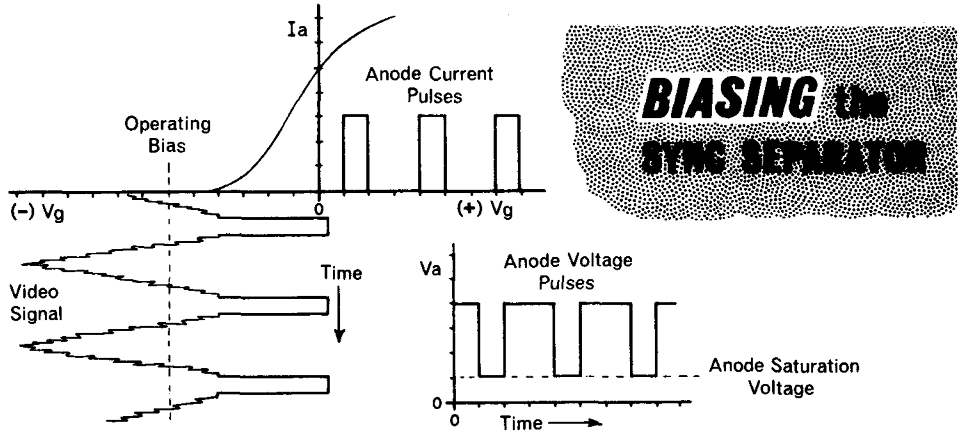
During the positive regions of the waveform, the valve grid takes on a positive polarity; and grid current starts to flow which causes C_1 to charge to the most positive excursions of the waveform. These are, of course, the tips of the positive sync pulses.

During the periods between successive sync pulses, the charge built up on C_1 begins to leak away slowly through the large-value (1 M) grid-leak resistor R_2. Before it has lost much of its charge, however, the next sync pulse arrives, and the charge lost through R_2 is replenished by grid current.

The net result is that the right-hand plate of C_1 acquires a steady negative polarity, and a steady negative voltage is developed across R_2. (This, you will no doubt have recognised, is the familiar "leaky-grid" method of producing a negative bias for the valve.)

The Sync Separator (*continued*)

The steady negative bias produced at the grid of the sync separator (typically, it is of the order of 2 or 3 V) is enough to bias the valve beyond the point of anode-current cut-off on the $I_a V_g$ curve—even though current still flows through the effective diode formed by the grid and the cathode. These biasing conditions are illustrated below.



To facilitate the build-up of cut-off bias, both the anode and screen-grid voltages of the pentode are deliberately made much lower than usual. This is achieved by supplying HT(+) voltage to these electrodes from potential divider circuits across the HT line. The anode is supplied via R_3 and R_4, and the screen grid via R_5 and R_6. Typical voltages so supplied are 96 V for the anode and 72 V for the screen grid.

Such operating conditions give the pentode a very short grid base—which means that a much smaller negative voltage is required on the grid in order to cut off the flow of anode current. (Note at this point that the negative voltage built up at the grid of the sync separator is used in many TV receivers to control the gain of the vision circuits. You will learn more about this when you come to study Automatic Gain Control.)

You will see from the illustration that the average value of the applied video signal "sits" on the negative bias which it creates at the grid of the pentode. By careful choice of the components C_1–R_2, R_3–R_4 and R_5–R_6, this bias can be made of such a value that *only* the sync pulses extend into the conduction region of the I_a/V_g curve, the remainder of the signal (*i.e.*, the picture signal content) being left in the cut-off region. This, of course, means that the pentode will only conduct during the period of the sync pulses, and that these will appear at the anode amplified and inverted.

Actually, a little more than this happens. You will notice that the sync pulses not only reach into the I_a-conduction region of the curve, but that they also extend right up to the grid-current region. Thus the maximum possible value of anode current will be caused to flow by the sync pulses; and this, coupled with the unusually low anode voltage, will cause the valve to saturate, or "bottom". The valve in fact bottoms well before the sync pulses reach the grid-current region, and clean steep-sided inverted sync pulses appear at the anode shortly after the sync pulses at the grid have started to turn-on anode current. In this way, some unwanted curvature of the edges of the sync pulses at the grid (caused by the series resistor R_1 and by the input capacitance of the pentode) is "straightened out" at the anode, thus preserving the sharp-sided pulses originally existing at the anode of the VA which are required to ensure positive separation of field from line pulses in following circuits and clean triggering of the field and line scanning generators.

The Sync Separator (*continued*)

Other points to be briefly noted about the sync separator are:

(*a*) The circuit relies on the fact that the video signal applied to its input is of negative-going polarity (picture signal increasing in a *negative* direction and sync pulses increasing in a *positive* direction). A signal of such polarity is also required by the cathode of the picture tube. Had this tube required a positive-going signal (as it might have done if it had employed grid modulation), the VA would have had to provide such a signal. This would not have suited the sync separator, and an extra valve would have been needed purely for the purpose of inverting the signal.

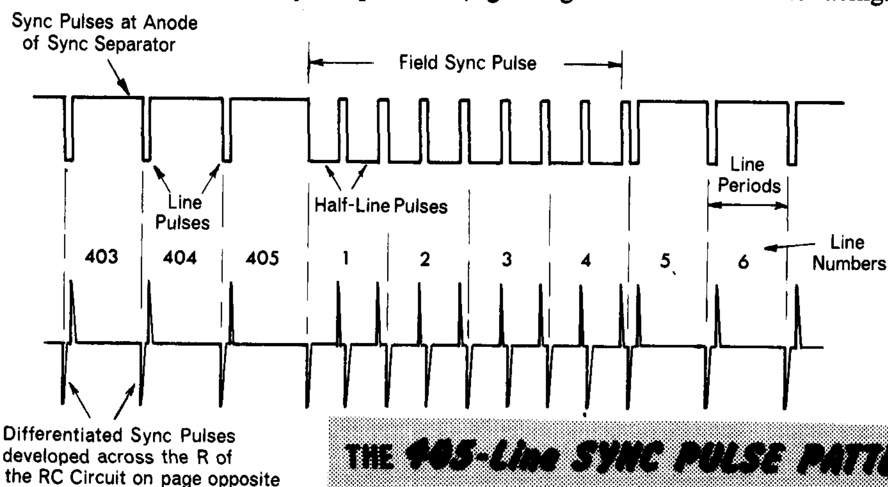
(*b*) The series resistor R_1 and the saturated operating condition of the pentode both contribute valuably to the suppression of noise pulses which might exist on top of the sync pulses.

(*c*) Since the sync separator "clips off" the top of the video signal to remove the sync pulses from the picture signal, the stage is sometimes referred to as the "**sync clipper**".

Separating the Line Sync Pulses

Now that the mixed sync pulses have been separated from the video signal, the next thing to do is to separate the field and the line sync pulses from one another.

Consider, first, the line sync pulses of the 405-line standard. They are simpler because they contain no equalising pulses to complicate matters. The illustration shows the sync pulse sequence which appears at the anode of the sync separator pentode at the end of an even-numbered scanning field. (For simplicity, the lines are numbered in the order in which they are produced, ignoring the demands of interlacing.)



THE 405-Line SYNC PULSE PATTERN AT THE END OF AN EVEN-NUMBERED SCAN

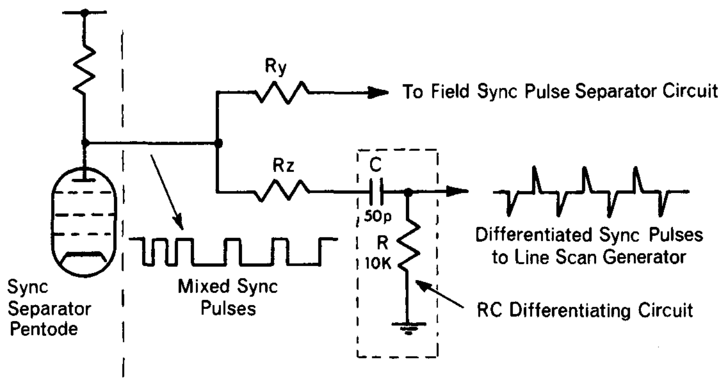
You see the field sync pulse divided into eight half-line pulses, each of 40 μs duration, and preceded and followed by a number of line sync pulses. The line scan generator requires sharp-edged pulses of short duration and negative polarity, occurring at line frequency even during the period of the field sync pulse. As things stand, the mixed sync pulses at the sync separator anode are of the correct polarity and of the correct frequency—including the necessary half-line frequency; but they are of different durations, and they are not short enough.

Separating the Line Sync Pulses (*continued*)

The solution is to pass the pulses through a type of ***RC* differentiating circuit** such as you learnt about in *Basic Electronic Circuits* (page 1.14). You will recall that such circuits consist of a capacitor connected in series with a resistor, the output being developed across the resistor. For an *RC* circuit to function as a differentiating circuit, the values of capacitance and resistance must be chosen so that five times the product of their time constant (5CR) is *less than* the duration of any pulse applied to it. In other words, 5CR must be less than t where t is the pulse duration.

In the 405-line system, the duration of the line sync pulses is about 9 μs. Thus the time constant of the differentiating circuit must be *not greater than* $t/5$, or 1·8, μs. In practice, the time constant is generally made even shorter than this, a value of 0·5 μs being typical. Representative values of C and R to produce a time constant of this value could be 50 pF and 10 k. The resulting 5CR product of 2·5 μs is, of course, well within the required limit of 9 μs.

In the circuit below, the resistor marked R_z is used to isolate the line sync separation circuit from the field sync separation circuit. The latter is, of course, also connected to the sync separator anode and has an isolation resistor, R_y, of its own.



SEPARATING the LINE SYNC PULSES

When the sequence of mixed sync pulses shown in the illustration opposite is passed through the differentiating circuit, a corresponding sequence of positive and negative spikes is produced, the whole sequence having a mean value of zero because the capacitor has removed any d.c. content. Every negative-going pulse of the input waveform produces two corresponding spikes at the output—one positive and one negative—the negative spike when the input waveform suddenly drops to a more negative value, and the positive spike when it returns to the no-pulse level. The important point is that *all* the spikes, whether positive or negative, are of exactly the same shape and duration—even though some were produced from pulses of very different duration.

The negative spikes, which occur at regular line and half-line intervals, are taken to the line scanning waveform generator, where they are used (either directly or indirectly) to synchronise its operating frequency. The positive spikes are either rejected (by means of a diode of some sort), or simply ignored because, as you will see, the scanning generator will generally be insensitive to pulses of positive polarity.

Separating the Line Sync Pulses (*continued*)

625-line Operation

The 625-line method of treating the line sync pulses is exactly the same, except that the value of the *RC* time constant needs to be *less than 4·7 μs.* In a dual-standard receiver, the time constant is therefore chosen to suit the 625-line sync pulses, for it will then automatically be short enough for the 405-line sync pulses. *No switching* is therefore necessary in this stage of the receiver.

Separating the Field Sync Pulses

You will recall that the field sync pulse is composed as follows:

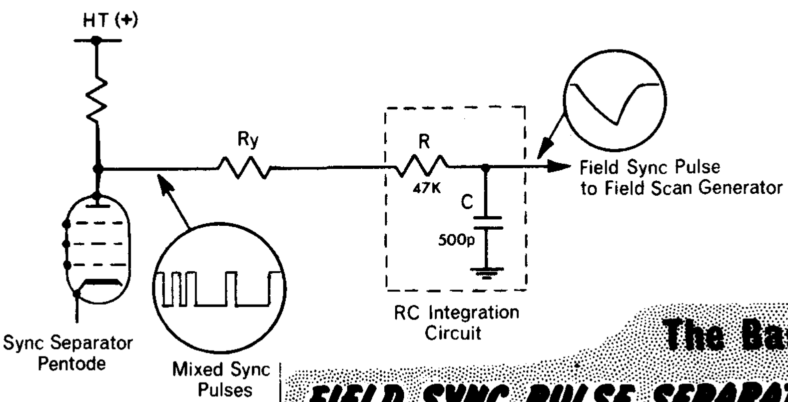
In the 405-line system, it consists of a cluster of eight pulses, each of 40 μs duration, occurring at twice line frequency. The field pulse is preceded and followed by ordinary line sync pulses of about 9 μs duration each.

In the 625-line system, the field sync pulse is composed of a cluster of six 27 μs pulses occurring at twice line frequency, preceded and followed by five equalising pulses of 2·3 μs duration also occurring at twice line frequency. The equalising pulse clusters are themselves preceded and followed by normal line sync pulses of 4·7 μs duration.

Thus in both systems the field sync pulse is made up of a carefully calculated cluster of other pulses of much shorter duration than its own. It is the job of the field sync pulse separator circuit to separate out these pulse clusters from the mixed sync pulses coming from the anode of the sync separator.

405-line Operation

The most widely-used method of separating out the field sync pulses is to pass the mixed sync pulses through a simple ***RC* integrating circuit** like that shown in the illustration below. The type of circuit was explained in *Basic Electronic Circuits*, pages 1.15 and 1.16. It functions in precisely the opposite manner to an *RC* differentiating circuit (if you are mathematically minded, you will know that integration is the opposite of differentiation).



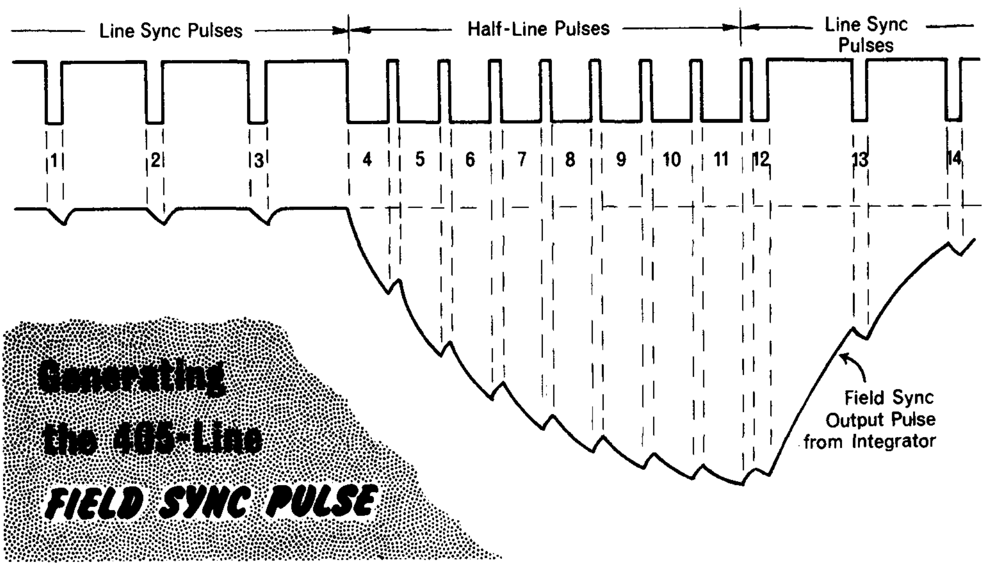
The Basic 405-Line FIELD SYNC PULSE SEPARATION Circuit

In an *RC* integration circuit, the input waveform is applied to a series arrangement of a capacitor and resistor, as before, but the output waveform is developed *across the capacitor*. The mixed sync pulses are applied to the integration circuit and, by careful selection of the values of capacitor and resistor to give the correct time constant, the field sync pulse required is developed across the capacitor.

Separating the Field Sync Pulses (*continued*)

The time constant of the *RC* combination in the integration circuit is chosen to be about 25 μs, which is comparable to the duration of the individual half-line pulses which make up the field sync pulse. Typical values of *C* and *R* to give such a time constant are 500 pF and 47 k respectively.

Consider what happens when a train of mixed sync pulses passes through the integration circuit, beginning at the moment when the last three line sync pulses of an even-line field are about to occur at the anode of the sync separator. The pulse sequence which follows is shown in the illustration. (To make the explanation easier to follow, the pulses have been numbered 1 to 14 just as they occur.)



When Sync Pulse No. 1 is applied to the integrating circuit, the capacitor begins to charge up through the 47 k resistor towards the peak voltage of the pulse, on a time constant of 25 μs. This rate of accumulation of charge, however, is slow compared with the short duration of the pulse (9 μs), and before the voltage across *C* has had a chance to build up to any significant amount, the pulse has ended. The small quantity of charge accumulated leaks away through *R*, having ample time to do so because the time between the line sync pulses is almost 100 μs. So by the time the next sync pulse arrives, *C* will have completely discharged.

When Sync Pulse No. 2 arrives, *C* again begins to charge up towards the peak voltage of the pulse, but is again prevented from charging very far—and the same thing happens when Sync Pulse No. 3 passes through.

But when the first of the broad half-line pulses arrives (Pulse No. 4), it is 40 μs long and C has a much longer time in which to accumulate charge. So a much greater charge is accumulated, and a much larger voltage across *C* is built up. At the end of Sync Pulse No. 4, *C* begins to discharge as before; but now only some 10 μs elapse before Pulse No. 5 arrives. Little charge is lost during this time.

Separating the Field Sync Pulses (*continued*)

The arrival of Pulse No. 5 allows C to recover not only the small amount of charge just lost, but also to acquire an additional charge—and the cumulative build-up of voltage across C continues for the remaining half-line pulses, so that at the end of Pulse Number 11, a substantial potential has been built up.

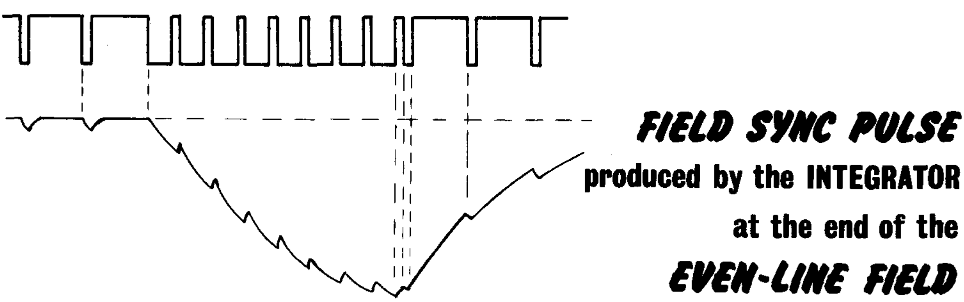
After Pulse No. 11, the usual 10 μs period elapses, during which a little of the charge on C leaks away; but the next pulse to appear (No. 12) is now an ordinary line sync pulse, whose duration is only 9 μs. Very little charge is regained by C during its presence, but after it has gone a full 100 μs elapses before Pulse No. 13 arrives. During this 100 μs, C loses most of the large charge it acquired during the presence of the half-line pulses, and during the remaining line sync pulses (No. 14 onwards) the situation reverts to that which existed at the end of Pulse No. 3.

Thus you will see that a significant voltage is built up in a series of jumps across C as each half-line pulse is applied to the integrating circuit, but at no other time. A signal is thus produced which is representative of the field sync pulse as a whole. This signal, although not yet particularly sharp-sided, can be made quite suitable for initiating the flyback operation of the field scanning generator.

Triggering Differences in the 405-line System

A field sync pulse such as the one just described is produced by the *RC* integrating circuit at the end of every field period in the 405-line system. But there is an important difference between the build-up times of the field sync pulses produced at the end of the odd-line and even-line fields. This difference can be seen in the illustrations of the output waveforms produced by the field sync pulse integrator circuit on this and the next page.

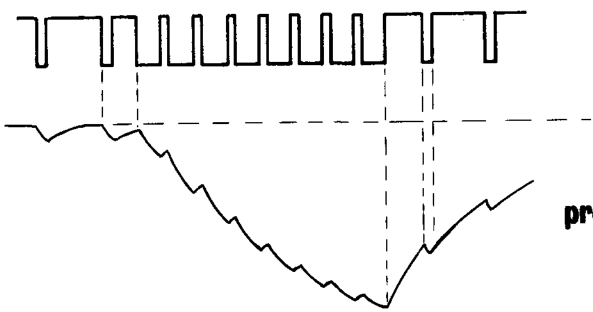
The difference arises in the following way. At the end of the *even-line field*, the field sync pulse sequence starts one full line period (about 100 μs) after the last line sync pulse has appeared. This period gives the integrator capacitor time enough to get rid of the small quantity of charge it has accumulated during the last line sync pulse, and ensures that it starts from a state of zero charge when the first of the half-line pulses which make up the field sync pulse arrives. At the end of the field sync pulse sequence, the first of the line sync pulses of the next (odd-line) field arrives only about 10 μs after the last of the half-line pulses, and so delays the decay of the charge accumulated by the capacitor; but the next line sync pulse does not arrive until 100 μs later—during which time the capacitor loses most of its charge. From then on, it acquires and loses equal amounts of charge as each line sync pulse arrives—as shown in the illustration below.



Separating the Field Sync Pulses (*continued*)

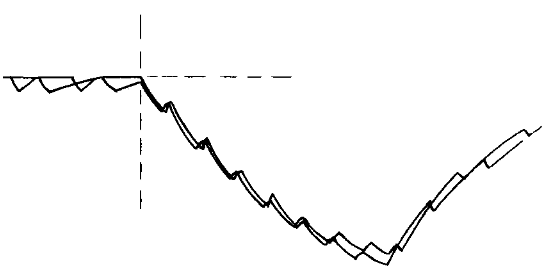
But at the end of the *odd-line field*, the field sync pulse sequence starts *half-way* along the last line, and therefore only about 50 μs after the onset of the last line sync pulse. The integrator capacitor has not enough time to get rid of the full charge it accumulated during the last line sync pulse, and some charge remains when the first of the half-line pulses arrives. The capacitor does not, therefore, start charging from zero when the field sync pulse sequence arrives, and this affects the shape of the leading edge of the field sync pulse.

A similar process takes place at the end of the odd-line field sync pulse sequence. The first line-sync pulse of the next (even-line) field occurs a full line period (100 μs) after the last half-line pulse, so now the integrator capacitor is allowed enough time to lose nearly all the charge it accumulated during the field sync pulse sequence, before the first line sync pulse arrives. This difference in time distribution of the first line sync pulse following the end of the respective field sync pulses accounts for the difference in the *trailing* edges of the field sync pulse waveforms produced by the integrator for the two successive fields.



FIELD SYNC PULSE produced by the INTEGRATOR at the end of the ODD-LINE FIELD

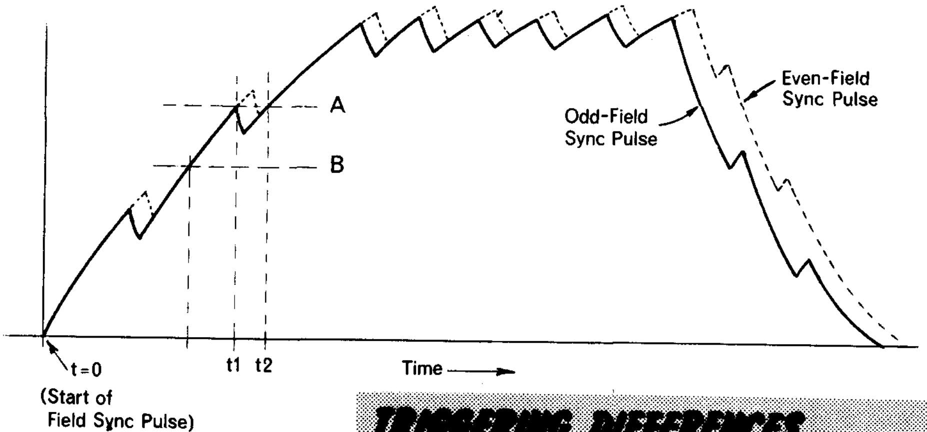
The extent of the difference in the leading and trailing edges of the pulses in the two successive field scans can be seen in the illustration below, which shows the two successive field sync pulses superimposed. Though it may not look much, the difference in the leading edges is quite enough to cause noticeable displacement of the two picture fields on the picture tube, and so to upset interlacing accuracy. (Remember that interlacing is perfect only when the lines from one field lie *exactly* midway between those produced by the preceding and succeeding fields.)



EVEN and ODD-LINE FIELD SYNC PULSES SUPERIMPOSED

Separating the Field Sync Pulses (*continued*)

The importance of this difference in the leading edges of the two field sync pulses in the 405-line system is shown in the following diagram—which again shows the field sync pulses from two successive fields superimposed.



TRIGGERING DIFFERENCES in the FIELD SCANS of the 405-Line SYSTEM

Assume that the clipping (or threshold) level of the limiter which follows the integrator (and which you will be reading about shortly) is set to point A on the waveform amplitudes. When the field scanning generator is supplied with a sync pulse from an even-line field, its flyback will be initiated at time t_1. When receiving an odd-line pulse, the flyback is not initiated until the later time t_2. It is this difference in the starting time of the generator which causes the displacement of alternate picture fields. Sometimes, when the difference between t_1 and t_2 is large, the interlacing becomes so bad that the lines produced from one field are only slightly displaced from those produced during the preceding field. This results in pairs of lines separated by large gaps—an effect known as *line pairing*.

Some field scan generators are also affected if the *period allowed for completion of the flyback* varies from one scan to another. Since this period is dictated by the duration of the field sync pulse, the difference between the trailing edges of successive pulses can also affect the operation of the generator. There is therefore urgent need of some means of minimising the difference between successive field sync pulses.

Examine the leading edges of the superimposed field sync pulses, and you will see that there are certain points on the waveforms (point B is an example) where the difference between t_1 and t_2 is less than it is at point A. To try to operate at such a critical point for long periods, however, is not satisfactory, because it relies on the sync pulses remaining at a near-constant amplitude—which they are most unlikely to do.

Many circuits have been devised to overcome the dissimilarity between successive field sync pulses in the 405-line system—most of them based on making all the pulses start from the same amplitude reference level (earth, for example), thereby overcoming the primary cause of the difference in the leading edges. Such circuits work quite well in practice, but the very fact that they are necessary is a major disadvantage of the 405-line method of processing the field sync pulse.

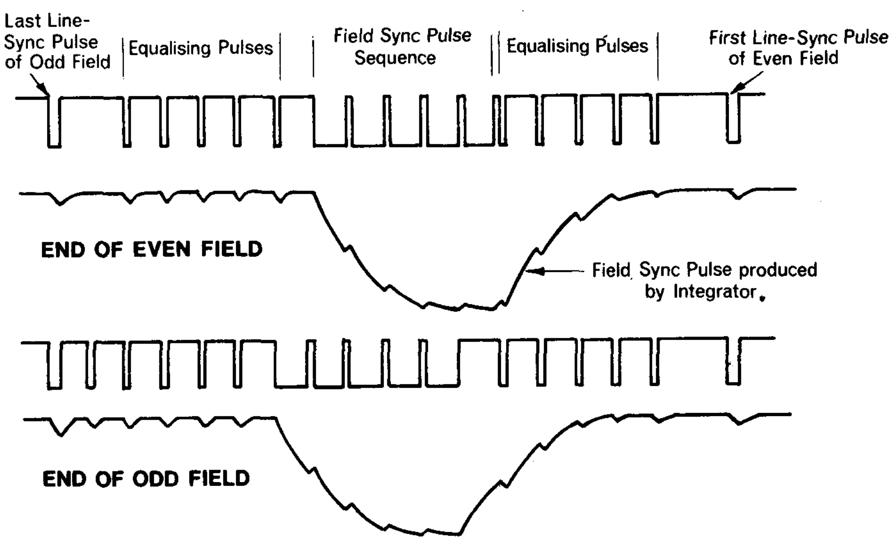
Equalising Pulses in the 625-line System

It was to avoid the drawbacks of the 405-line method of reconstituting accurate field sync pulses in the receiver that the *equalising pulses* were introduced into the 625-line system.

You have already learnt about the shape and duration of these pulses in Part 1 (page 1.78). Summarising, they are made to occur in two clusters, each occupying a time interval equivalent to 2½ line periods (about 128 μs). One cluster appears immediately *before* the arrival of the field sync pulse sequence, and the other immediately *after* it. Each cluster contains five pulses which occur at twice line frequency (the same rate as the half-line pulses which make up the field sync pulse sequence), but which are individually of only half the duration of the ordinary line sync pulses.

Being of such short duration (2·5 μs), equalising pulses have only a small individual energy content, and the integrating capacitor of the field sync pulse separation circuit therefore acquires only a small quantity of charge during the time each pulse is present. The charge on the integrating capacitor at the beginning and end of the field sync pulses is thus allowed to build up and leak away at rates that leave it at a level which is practically identical for both odd and even-line fields at the crucial moments of onset of both the field sync pulse itself and of the first line sync pulse of the succeeding field. In other words, the charge content of the integrating capacitor (and therefore the voltage developed across it) is quickly *equalised* for successive fields.

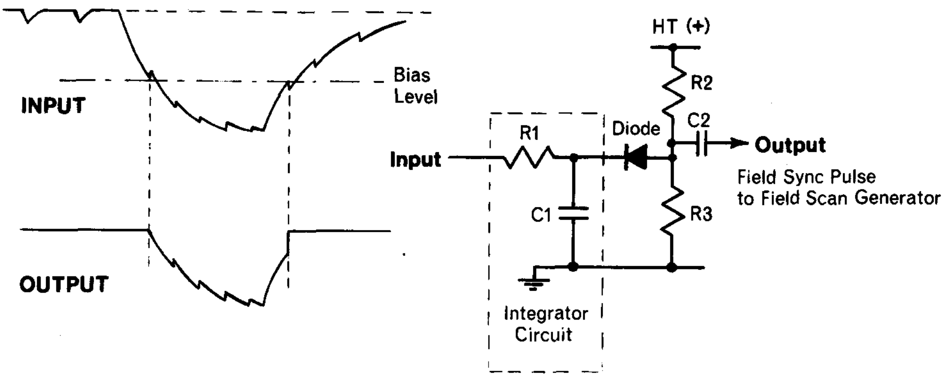
The illustration shows the field sync pulse sequence for two successive odd and even-line fields of the 625-line system. Note how the shapes of the corresponding field sync pulses produced by the integrator circuit are affected by the presence of the equalising pulses. Although the voltage across the integrating capacitor is different for the two fields at the time of arrival of the first equalising pulse, it has settled down to near-zero by the time the field sync pulse sequence starts. At the end of the field sync pulse sequence, the voltage is also given time to settle down to near-zero by the time the first line sync pulse of the next field arrives.



The *Effect* of the *EQUALISING PULSES* in the 625-Line SYSTEM

The Field Sync Pulse Limiter

In both line systems, the waveform produced by the field sync integrator circuit contains small-amplitude pulses produced by the line sync pulses. It is important that these pulses should be removed before the integrator waveform is applied to the field scanning generator lest its flyback be initiated before the arrival of the genuine field sync pulse. Their removal can be achieved by passing the integrator waveform through a simple diode limiter circuit, similar to that shown in the illustration below.



The Field Sync Pulse LIMITER Circuit

The limiter usually consists of a semiconductor diode whose anode is connected to a potential which is negative with respect to the potential present at its other electrode. The potential to which the anode of the diode is returned is determined by the value of the two resistors R_2 and R_3 which form a potential divider across the HT(+) supply. The actual value of the potential is determined by the equation:

$$V = \frac{R_2}{R_2 + R_3} \times V_{HT}$$

Connected in this way, the diode has reverse bias. It will therefore not conduct until the amplitude of the negative-going signal applied to its cathode exceeds the magnitude of the bias. The bias potential is carefully chosen to be somewhat larger than the maximum amplitude of the unwanted line sync pulses present in the integrator waveform. These pulses therefore all lie below the bias potential, and so below the threshold at which the diode can conduct (often called the "clipping level" of the limiter).

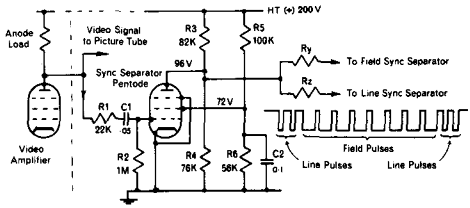
The amplitude of the wanted field sync pulse, however, is considerably greater than the bias potential, and the diode is able to conduct for almost the entire duration of the pulse save for the small area lying below the bias threshold.

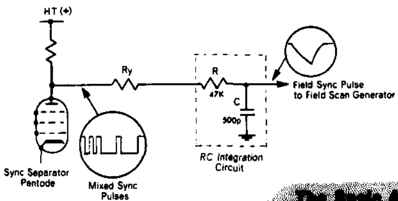
When the diode conducts, the field sync pulse, minus the unwanted line sync interference pulses, is passed to the coupling capacitor C_2, and thence to the field scanning generator.

REVIEW of Sync Pulse Separation

The sync separator stage accepts the negative-going video signal applied to it from the video amplifier and extracts from it the line and field sync pulses.

These two pulse chains are then separated from one another, and shaped so as to become suitable for synchronising the frequencies of the line and field scan generators with the corresponding control frequencies built into the signal transmitted from the studio.



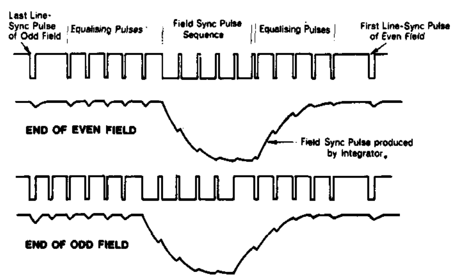


The Basic 405-Line FIELD SYNC PULSE SEPARATION Circuit

Separation of the *field sync pulse* from the train of mixed sync pulses fed into the sync pulse separator is achieved by a simple RC integration circuit. The time constant of this circuit is carefully chosen so that an output voltage is generated by it only during the presence of the half-line pulses which make up the field sync pulse.

The *equalising pulses* used in the 625-line system effectively obviate the interlacing problems which, in the 405-line system, are caused by the dissimilarities of alternate field sync pulses.

The equalising pulses ensure that the amount of charge retained by the integrating capacitor used in the field sync pulse separation circuit is identical at the start of every new field sync pulse.



The *Effect* of the EQUALISING PULSES in the 625-Line SYSTEM

§18: THE SCANNING GENERATORS

You know that every complete picture appearing on the picture tube of a TV receiver is built up by modulating the intensity, or brightness, of two interlaced and successively presented scanning rasters. Each raster, or half-picture, is known as a *field* and occurs 50 times a second. It is made up of 202½ (in the 405-line system), or of 312½ (in the 625-line system), nearly horizontal parallel lines (ignoring in both cases the few lines which are lost during the field blanking interval). In the absence of any picture signal, the lines which make up the rasters are of uniform brightness—as you can see on most TV receivers by removing the aerial, or switching to an unused channel, and turning-up the *Brightness* control.

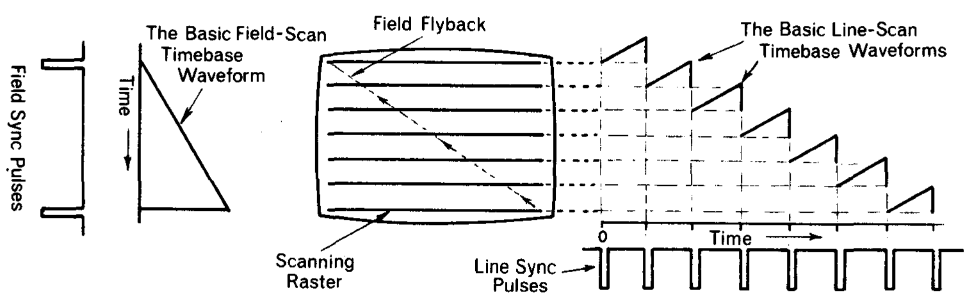
A raster is produced by displaying a rapidly-recurring horizontal timebase, which is at the same time much more slowly deflected from the top to the bottom of the tube. Every **line** begins at the left-hand side of the tube, and when it reaches the right-hand side is rapidly returned to the left ready to start again a little below its predecessor. The left-to-right movement of the scanning beam is known as the **line scan** and the fast right-to-left movement as the **line flyback.**

The slower vertical deflection from top to bottom of the picture tube is called the **field scan.** It starts from the top left-hand corner of the tube and ends midway along the last line at the bottom of the raster. (On alternate rasters it starts from midway along the first line and terminates at the end of the last line.) Wherever it terminates, the scanning beam is rapidly returned to the top of the tube in time for the first line of the next field scan to begin. This rapid return to the top of the tube is known as the **field flyback.**

The horizontal lines, or *timebases,* of the raster are produced by a circuit known as the **line scan generator.** This is a timebase generator, or oscillator, operating at a repetition frequency of 10·125 kHz (in the 405-line system) or at 15·625 kHz (in the 625-line system). It produces in either case a nearly linear sawtooth waveform of current which, after appropriate development, is applied to the horizontal or **line scanning coils** surrounding the neck of the picture tube.

The slower vertical deflection of the scanning lines is produced by a second timebase generator called the **field scan generator.** This operates at the much lower frequency of 50 Hz and also produces a near-linear sawtooth of current which, again after development, is applied to the vertical or **field scanning coils** also situated round the neck of the picture tube.

The repetition rates and starting times of the line and field scan generator waveforms are synchronised with those of the received picture signals by means of the line and field sync pulses which you have just seen being extracted from the video signal at the sync separator stage.



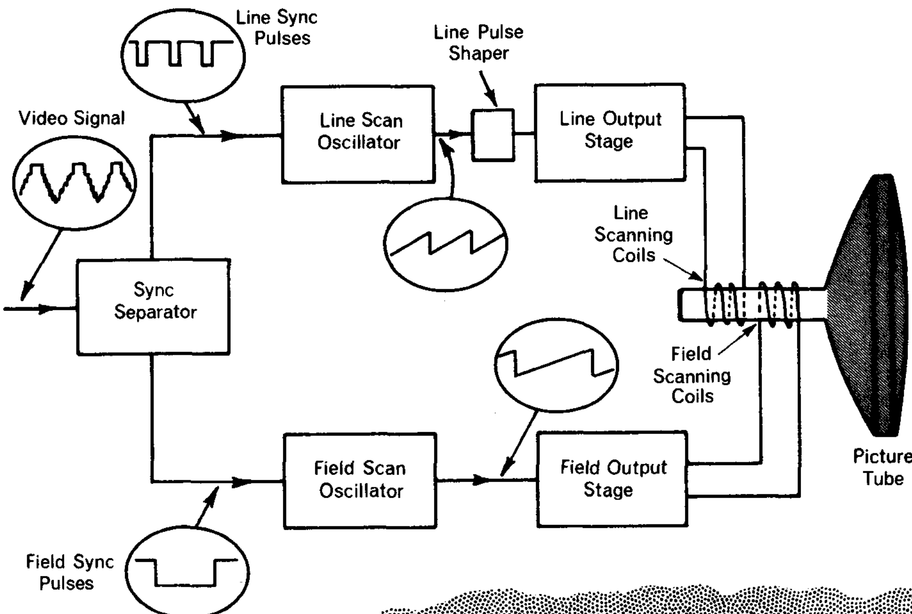
The Line and Field Scanning Circuits

The concern of this Section is to show you how the horizontal (line) and vertical (field) scans of the electron beam across the screen of the picture tube are originated, and how they are synchronised with the respective timebases used in the studio camera by the line and field sync pulses which you now know are available. In the two following Sections, you will see how the field scan, and then how the more complicated line scan, waveforms are developed until they possess the characteristics of power and shape which they need when they are applied to the scanning coils of the picture tube.

To put the matter more formally, the job of the line and field scanning circuits is to generate waveforms of current of the correct shape and at the prescribed repetition rates, and to deliver these currents to the line and field scanning coils with sufficient power to generate full-width and full-height scans of the picture tube.

The process normally takes place in three stages. First, a low-power oscillator, synchronised with the incoming line or field sync pulses, is used to generate the basic scanning waveform. Second, this waveform is raised to the required power level by a power amplifier. Third, an impedance-matching transformer is used to couple the waveform from the power amplifier to the scanning coils. The power amplifiers plus the transformers are generally known as the **line and field output stages**: the matching transformers themselves as the **line and field output transformers.**

The basic arrangement is shown in the block diagram below. For simplicity at this stage, the sawtooth waveforms at various points are shown as being truly linear. In practice, it is often necessary to use sawtooth waveforms which are appreciably non-linear in shape.



BLOCK DIAGRAM of the LINE and FIELD SCAN Circuits

The Line and Field Scan Generators

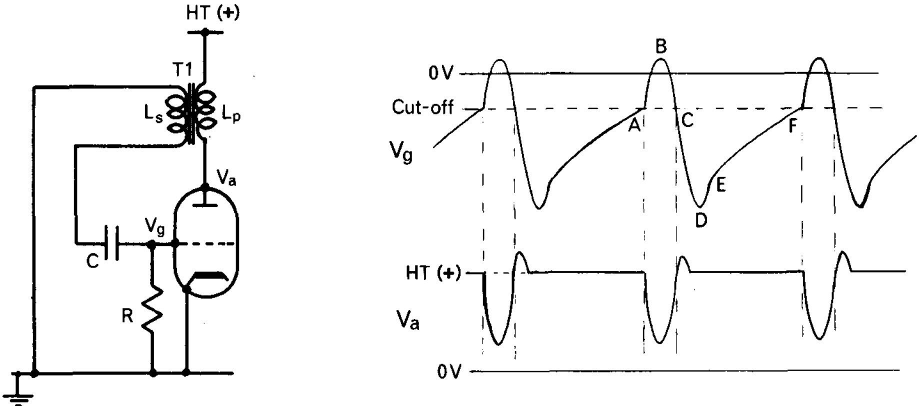
The waveform generator in both the line and the field scanning circuits is a separate oscillator, nearly always either of the *blocking* or of the *multivibrator* type. In a given TV receiver, both oscillators may be of the same type, or oscillators of different types may be used to generate the line and field scans respectively.

The line oscillator circuit is known alternatively as the *line scan oscillator*, the *horizontal oscillator* or the *line scan generator*; the field oscillator circuit as either the *field scan oscillator*, the *vertical oscillator* or the *field scan generator*. Here they will be consistently called the **line scan generator** and the **field scan generator** respectively.

Detailed descriptions of how both the blocking oscillator and the multivibrator are used as pulse generators are given in Section 12 of *Basic Electronic Circuits* (pages 1.69 to 1.87), so only a brief account of the method of operation of each will be necessary here. Let us start with the blocking oscillator.

The Blocking Oscillator

This type of oscillator has been used in TV receivers more than any other, because of its simplicity and good frequency stability. Only a single valve (usually a triode) or a single transistor is necessary. In the valve type the triode often forms half of a dual valve of which the other half (typically a pentode) forms the line/field output stage.



The BLOCKING OSCILLATOR and its Operating Waveforms

Over the region A–B, as you can see, anode current in the valve is increasing, and a positive voltage is fed back to the grid via the transformer T_1 and the components C and R. This positive feedback causes increasingly more anode current to flow, until no more is available from the cathode. At this point the valve is saturated and anode current is steady (waveform at point B).

Also at this point in the operation, however, transformer action ceases (you know from *Basic Electricity*, pages 3.49 to 3.52, that a transformer only works when the current through its primary is a *varying* one). When transformer action ceases, so does the positive feedback to the grid. Without this feedback, anode current starts to fall—and transformer action once more commences.

The Blocking Oscillator (*continued*)

This time, however, because anode current is falling, a *negative* voltage is fed back to the grid, so that even less anode current is able to flow. The action is thus cumulative while grid voltage is rapidly driven beyond its cut-off value (point C) and anode current flow stops altogether. The energy stored in the transformer inductance, however, causes the negative feedback to continue, until a minimum value is reached at point D.

With the valve cut off and not conducting, the charge which the capacitor C acquired when the grid was driven positive now begins to leak away through the discharge path formed by R and the very low resistance of the secondary winding (L_s) of the transformer. This discharge is represented by the area D–E–F of the waveform. The time comes during the discharge when the voltage across R (which is the same thing as the grid voltage) reaches the cut-on point of the valve. Anode current starts to flow again, and the whole cycle is repeated.

The controlling influence in the operating frequency of the blocking oscillator is *the rate at which C discharges*, and hence the time taken by the voltage across R to reach the cut-on point of the valve. The faster the discharge rate, the faster the operating frequency, and *vice versa.*

In view of the importance of ensuring that the operating periods of the line and field scan generators in the receiver should be the same as those in the studio camera, it is obviously necessary to be able to adjust "coarsely", as it were, the frequencies of the scanning generators in the receiver so that "fine" synchronisation may be applied to them by the line and field sync pulses.

The usual method of "coarse" adjustment of the frequency of a blocking oscillator is to vary the value of the discharge resistor R. In practice, this control is only infrequently used, and for this reason it is usually of the preset type and situated at the back of the receiver.

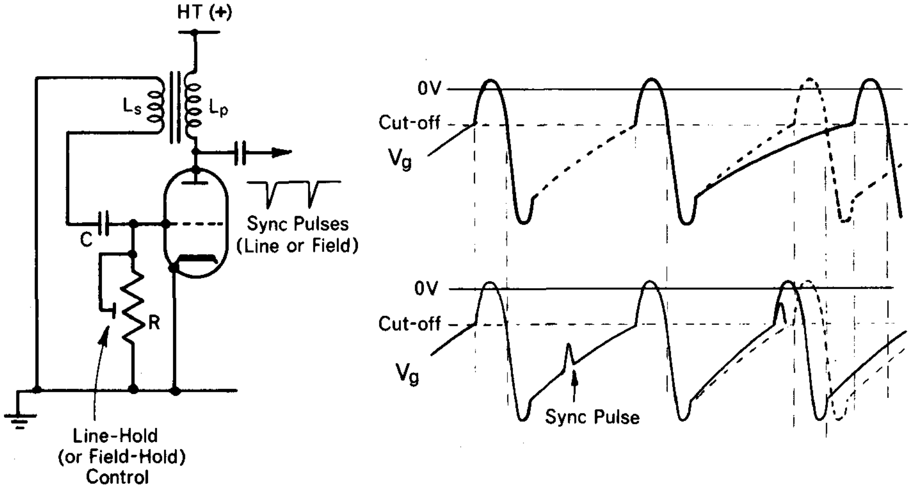
When the control is associated with the line scan generator it is known as the **Line Hold** (or sometimes as the *horizontal lock*). When it is associated with the field scan generator, it is known as the **Field Hold**, or *vertical lock.*

The illustration on the next page shows the basic arrangement of a typical frequency control, and the effect on the operating waveform of the "fine" adjustment applied by the sync pulses as they arrive.

The negative-going pulses from the line or field sync pulse separator circuits are applied (directly or indirectly) to the anode of the oscillator, thence via the transformer and the components C and R to the grid, where they are inverted. These now-positive-going pulses cause premature discharge of C, and the operating frequency of the oscillator is speeded up until it is brought into step with that of the sync pulses. When synchronisation is perfect, the sync pulses occur at a point on the waveform coincident with that at which it passes through the cut-on value of the grid voltage.

Work out for yourself what happens when they occur *after* grid current has started to flow, and when the operating frequency of the oscillator needs to be *slowed down* so as to coincide with that of the sync pulses themselves.

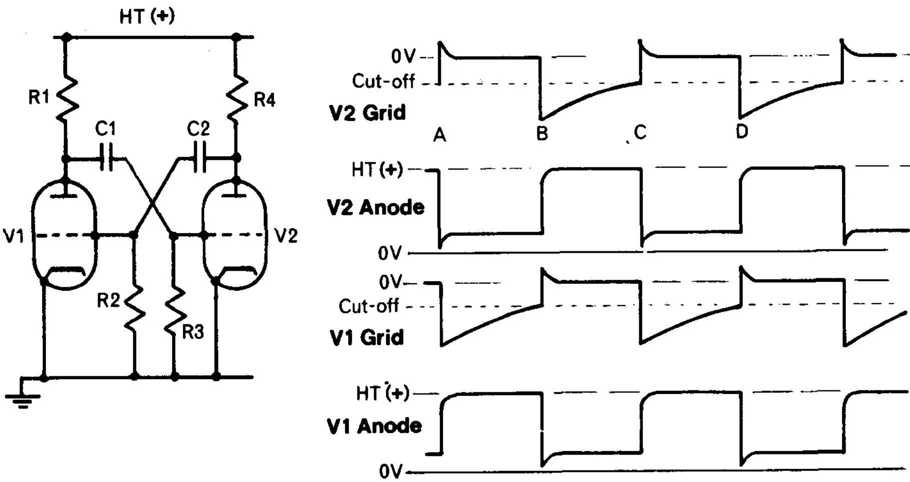
The Blocking Oscillator (*continued*)



FREQUENCY CONTROL OF A Blocking Oscillator AND THE EFFECT ON IT OF THE SYNC PULSES

The Multivibrator Oscillator

Unlike the blocking oscillator, the multivibrator is a device which requires the use of either *two* valves or *two* transistors for its operation. To offset this economic disadvantage, it makes use of simple *C* and *R* coupling components to provide the necessary feedback, in place of a comparatively expensive transformer.



Basic Circuit and Waveforms of the MULTIVIBRATOR Oscillator

The Multivibrator Oscillator (*continued*)

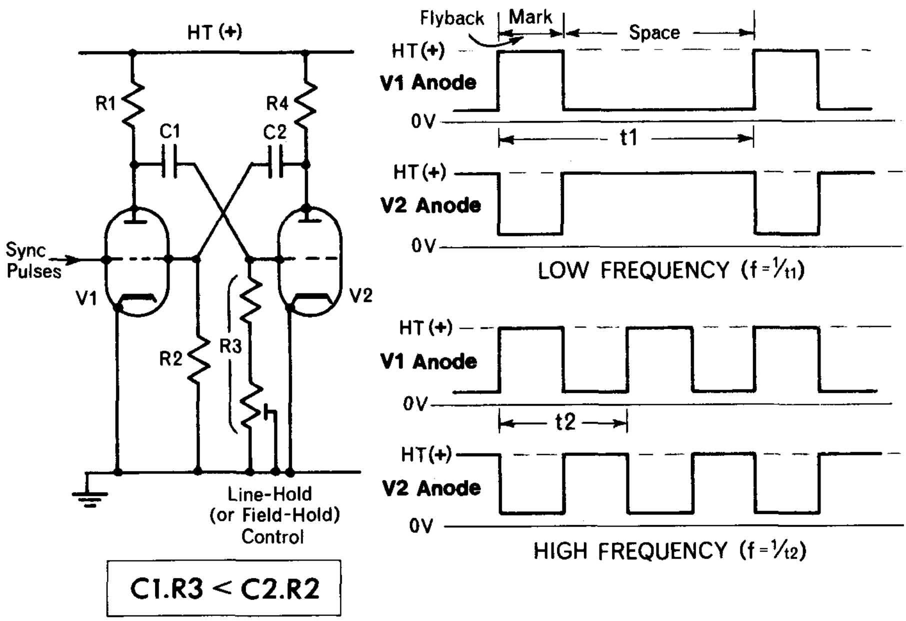
At any point during the operation of the multivibrator circuit shown at the foot of the previous page (apart from the exceedingly short change-over periods) one valve is conducting heavily at saturation point, and the other is cut off. The *rate at which the valves change their operating states* defines the operating frequency of the circuit. It is determined by the values of the *C* and *R* coupling components, C_1R_3 and C_2R_2 respectively.

In a "symmetrical" circuit, the time constants formed by C_1R_3 and C_2R_2 are equal, as are the values of the anode load resistors R_1 and R_4. With this type of circuit, the "on" and "off" period of each valve is identical, and the waveforms produced at the anode of each are of the same duration, but 180° out of phase.

Suppose, however, that the time constant formed by C_1R_3 is made *shorter* than that formed by C_2R_2. The multivibrator now becomes "asymmetrical". V_2 will be cut off for a longer period than will V_1, and the waveform produced at its anode will be of shorter duration than will be that at the anode of V_1.

This form of asymmetry can be brought about *either* by reducing the values of C_1, or of R_3, or of both of them; *or* by increasing the values of C_2, of R_2, or of both. However it is done, the Mark-to-Space ratio (*Basic Electronic Circuits*, page 1.8) will be varied, as also will the operating frequency.

If it is desired to vary the operating frequency without affecting the mark-to-space ratio, then either C_1 *and* C_2, or R_2 *and* R_3 must be varied together by the same amounts.



The *Asymmetric* Multivibrator

The Multivibrator Oscillator (*continued*)

When the multivibrator is used as the line or field scan generator in a TV receiver, it is required to produce a constant-duration waveform at a frequency which can be adjusted over a comparatively small range by the line or field hold controls. In other words, it must have an asymmetric output waveform, the frequency of which must be adjustable.

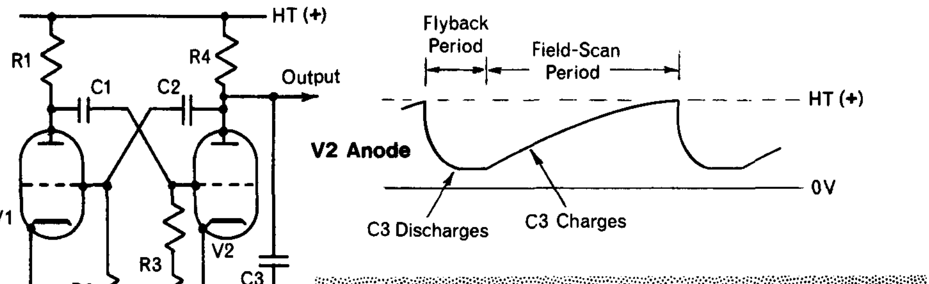
This is usually achieved in the multivibrator by making R_3 adjustable, and by choosing the value of C_1 so that the C_1R_3 time-constant is different from that of C_2R_2—as shown in the illustration on the last page, which would be suitable as a line or field scan generator.

Synchronisation of the multivibrator by the negative-going line or field sync pulses is achieved by applying them (directly or indirectly) to the grid of the valve which is normally conducting during the scan period and cut off during the flyback period. The arrival of a sync pulse causes the valve to cut off. This in turn causes the other to cut on—and so to initiate the flyback.

The operation of the synchronised multivibrator, in both its valve and transistor forms, is described at greater length on pages 1.78 to 1.81 of *Basic Electronic Circuits.*

Shaping the Field Scan Waveform

As you will see in the next Section, the scanning waveform required at the input of the field output stage is of a shape known as an exponential sawtooth. This particular shape cannot be obtained directly from either the blocking oscillator or the multivibrator types of waveform generators, so it is necessary to produce the desired shape by other means. It can be done quite simply in either type of waveform generator, usually with the aid of a single extra capacitor connected across the output terminal. The illustration shows how this is done in the case of the multivibrator.



SHAPING the Field Scan Waveform

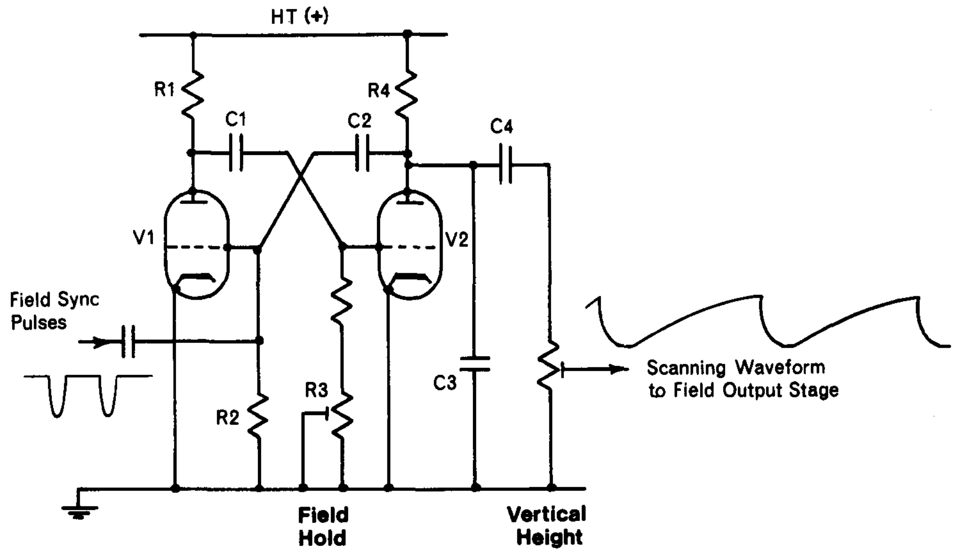
If the extra capacitor C_3 were not there, the waveform produced at the anode of V_2 would be of rectangular shape, as it was in the illustration on the last page. With C_3 connected, however, the output waveform is modified in the following way. When V_2 is not conducting, C_3 is fully charged to the voltage of the HT supply. But when V_2 is cut on by the cross-coupling from V_1, C_3 discharges very rapidly through the valve (which is what gives the sharp vertical edge to the waveform at the beginning of the flyback period).

When V_2 once more cuts off, C_3 is again free to charge up to the HT supply. It does so through the anode load of V_2, on a time-constant of C_3R_4 seconds.

Controlling Picture Height

The height of the picture displayed on the picture tube can be controlled by varying the amplitude of the exponential sawtooth waveform applied to the field output stage. The control which enables this to be done is called, for obvious reasons, the **Vertical Height** (or simply **Height) Control.** Because it seldom requires adjustment, it is of the preset type and is usually situated at the rear of the set.

The control takes the form of a simple potentiometer connected so that the field scan waveform is developed across it. It operates exactly like the volume control in a radio receiver.



A COMPLETE FIELD SCAN GENERATOR CIRCUIT

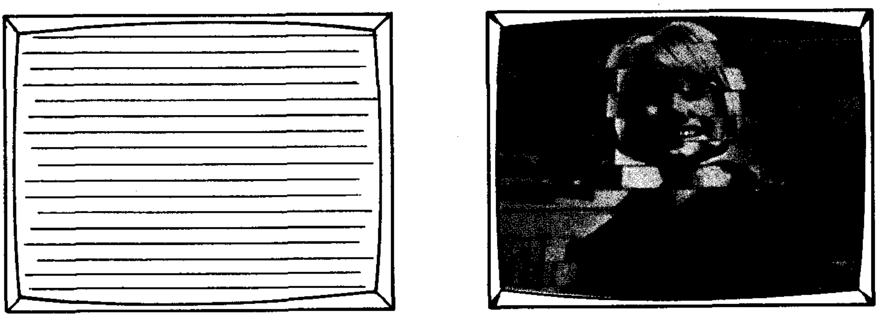
The illustration shows a typical arrangement for a complete field scan generator circuit, including the vertical height control just discussed. The capacitor C_4 is a large-value blocking capacitor serving to isolate the high potential at V_2 anode from the height control, and from the stages which follow.

Although a multivibrator type of generator has been shown, one of the blocking-oscillator type could have been connected in a similar way.

Flywheel Synchronisation

Direct connection of the sync pulses to the oscillator of the field scan generator is still standard practice. But in the *line* scan generator, synchronisation of the operating frequency by direct application to the oscillator of the spikes of the line sync pulses can give rise to an undesirable effect known as **line tearing**, and in most modern TV receivers a more complicated technique called flywheel synchronisation is applied.

The trouble with direct application of the line sync pulses to the line scan generator is that noise pulses which are often, despite all precautions, still present among the sync pulses can have as much effect on the oscillator as do the line sync pulses themselves—with the result that initiation of the flyback becomes erratic whenever the noise pulses (from, *e.g.*, unsuppressed car ignitions, electric drills and some types of electric shavers) are present. Disruption of normal synchronisation in this way causes random displacement of the scanning lines, or groups of lines, because of variation in their respective starting times. This gives the appearance of ragged edges to the picture, making it look like the edges of a piece of torn material—whence the name *line tearing* applied to this form of distortion.



LINE TEARING

In more modern TV receivers, the frequency of the line scan generator is no longer controlled directly by the line sync pulses but by a circuit which *compares* the frequency of the generator with that of the line sync pulses. Whenever the frequency of the generator differs from that of the line sync pulses, the comparator circuit produces a d.c. voltage which is used to alter the frequency of the generator in such a way as to bring it back into step. The greater the difference between the compared frequencies, the larger the controlling voltage produced. The polarity of the control voltage depends on whether the frequency of the generator is greater or less than that of the line sync pulses.

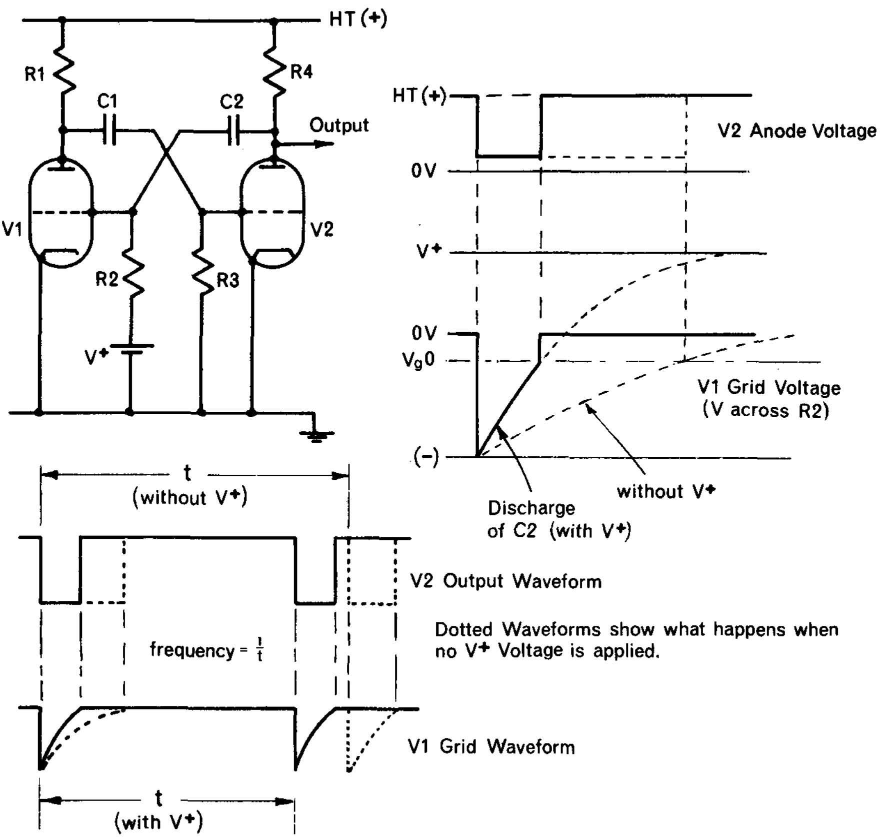
To prevent a control voltage being produced whenever a burst of interference pulses occurs, a deliberate time-delay is introduced so that the control is applied only gradually. Application in such a way gives the control a kind of "flywheel" effect and enables it to override or ignore sudden, but comparatively minor, changes in frequency such as those produced by impulsive interference.

If the interfering noise is sustained (as it would be if it came from an electric drill), flywheel action will lose much of its effectiveness. The resulting line tearing will still be less than it would otherwise have been, however; for with flywheel synchronisation it is the *average* frequency variations which are applied to the oscillator, and this average tends to even out the sharper variations of frequency caused by pulses of noise.

Flywheel Synchronisation (*continued*)

You will see that two distinct operations are necessary in a flywheel sync circuit. The first is the operation of comparing the frequencies of the two waveforms (sync pulse frequency with line-scan frequency) and generating a d.c. voltage proportional to the difference between them. The second operation is that of controlling the frequency of the line scan oscillator by means of the d.c. controlling voltage produced in the first operation.

Consider, first, the second operation, and see how the frequency of an oscillator circuit can be controlled by means of a variable d.c. voltage. Since the multivibrator tends to be more widely used as a line scan generator than does the blocking oscillator, start with the basic M/V circuit and see what happens when the resistor R_2 is removed from earth and connected instead to a positive voltage (represented in the illustration below by a battery connected in series with R_2).



USING A D.C. VOLTAGE to Control the Frequency of a Multivibrator-Type Oscillator

Flywheel Synchronisation (*continued*)

At the instant when V_2 suddenly conducts, the fall in its anode potential is communicated to the grid of V_1, and V_1 is cut off. At the instant before V_2 was cut-on, C_2 was fully charged, with its right-hand electrode having charged through the anode load of V_2 to the potential of the HT supply and its left-hand electrode held at about zero volts by the grid current flowing heavily in V_1.

When V_1 is cut off and V_2 starts conducting (*i.e.*, at the moment of switch-over), the right-hand electrode of C_2 is reduced from the high HT voltage to a very much lower potential. With V^+ connected, however, instead of its left-hand electrode dropping sharply to about zero volts and remaining there for a while, it first drops and then immediately tries to "aim" towards the positive voltage which is present at the lower end of R_2.

In other words, after C_2 has discharged very rapidly to the same voltage as it did in the simple circuit, it now seeks to *re-charge* almost at once towards the additional voltage applied to R_2. But no more time than before is available for this re-charge, for the time-constant has not changed and the voltage across C_2 must still rise to 66% of the voltage applied to it within a period of time equal to one time-constant.

Thus the rate at which C_2 re-adjusts its charge must increase; and this means that the value of V_{go} will be reached sooner. When V_{go} is reached, as you know, the circuit switches over to its other state; so if V_{go} is reached more quickly than before, it means that the frequency of the circuit has increased.

It follows that the frequency of an oscillator circuit is increased when a positive voltage is applied to the lower end of R_2; and the larger the value of this voltage, the greater will be the increase in frequency. It is thus possible to control the frequency of the line scan oscillator by applying a variable d.c. voltage to the lower end of R_2.

Note, by the way, that the same degree of frequency control could be achieved by applying the d.c. voltage to the lower end of R_3, instead of to R_2. This is not done, however, because C_1 and R_3 are associated with the *scan* period of the waveform, and it is the *flyback* period which is of importance—as you will shortly see.

Frequency Comparison Circuits

Now that you know how the frequency of the line scan oscillator can be controlled by means of a variable d.c. voltage, the next step is to see how such a voltage can be produced when the frequencies (or phase relationship) of two different signals are compared.

Circuits which compare signals in this way are given a variety of titles, such as frequency (or phase) comparators, frequency (or phase) discriminators, frequency (or phase) detectors, and coincidence detectors. Of the many circuits which have been developed over the years to do this sort of job, British TV receiver manufacturers tend to favour two particular types. In what follows, these two types will be known as the **coincidence detector** and the **phase detector** respectively, though you may find both of them called by other names in other literature.

We will begin by looking at the coincidence detector.

The Coincidence Detector

The basic circuit of a simple coincidence detector is shown in the illustration. The circuit consists of a pentode valve to which two separate input signals are applied, one to its control grid (G_1) and the other to its screen grid (G_2). Both signals are positive-going; and, for convenience in differentiating between the two, one is shown as being of longer duration than the other.

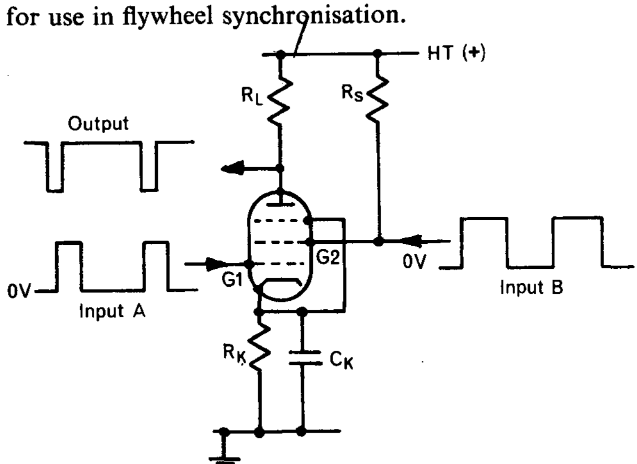
The screen grid resistor (R_s) and the cathode bias components (R_k and C_k) are chosen so that the valve passes only a very small anode current when neither signal is present. When only Input A pulses are present, the anode current of the valve is increased slightly during the period of each pulse. This causes a correspondingly small fall in the voltage at the anode, by reason of the increased voltage drop across the anode load resistor (R_L).

Similarly, small increases in anode current (and corresponding falls in anode voltage) occur when only Input B pulses are present.

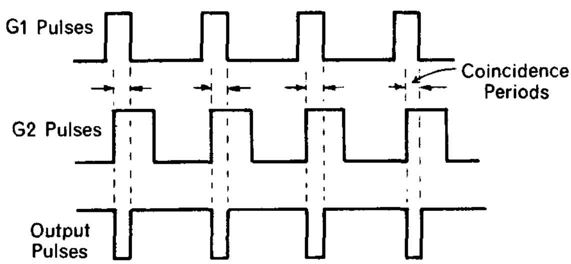
When both Input A *and* Input B pulses are present, their combined influence causes a large increase in anode current to flow, *but only during the period when both pulses are actually coincident.* Outside the limits of coincidence the anode current of the valve reverts to its normal single-pulse-present values.

The increase in anode current flow which results from the coincidence of the two pulses causes a negative voltage pulse to be produced at the anode of the valve, the duration of which equals the period of coincidence.

You must now see how such a simple coincidence detector needs to be developed for use in flywheel synchronisation.



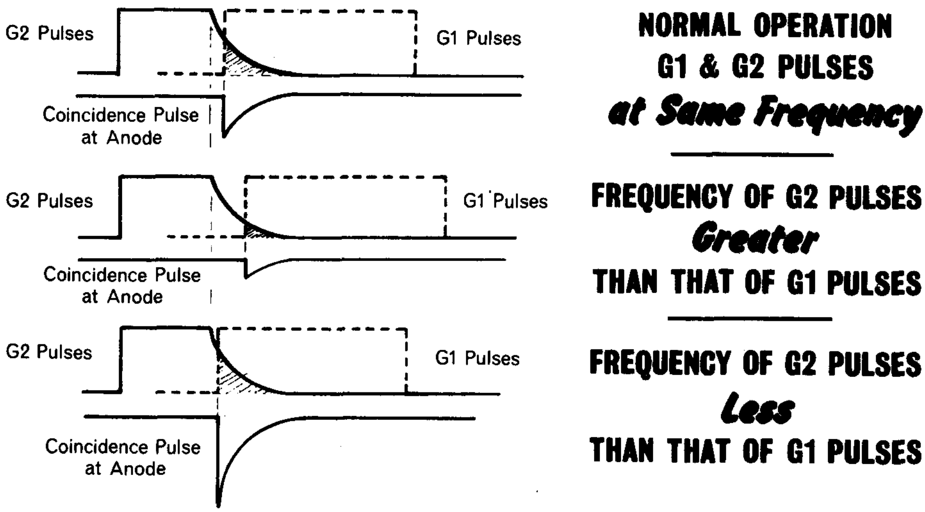
The Basic COINCIDENCE DETECTOR



The Coincidence Detector (*continued*)

When the coincidence detector is used for flywheel synchronisation, the Input A pulses to G_1 are derived from the line scan oscillator and are coincident in time with the flyback period of the line scan waveform. These pulses are truly rectangular in shape, having sharp leading and lagging edges. The Input B pulses to G_2 are derived from the normal line sync pulses (with which they are exactly coincident in time) through a pulse shaping and inverting circuit which will be described later on. This latter circuit, as you will see, gives the G_2 pulses a sharp leading edge and a flat top, but a sloping lagging edge.

When the TV receiver is functioning normally, the phase relationship between the two waveforms is such that the leading edge of the G_1 waveform arrives at a point about one-third of the way down the slope of the lagging edge of the G_2 waveform. The resulting coincidence pulse at the anode of the valve is negative-going, and has the same shape as that of the coincidence area (which corresponds to the period of duration of anode current flow, and is shown shaded in the illustration below).

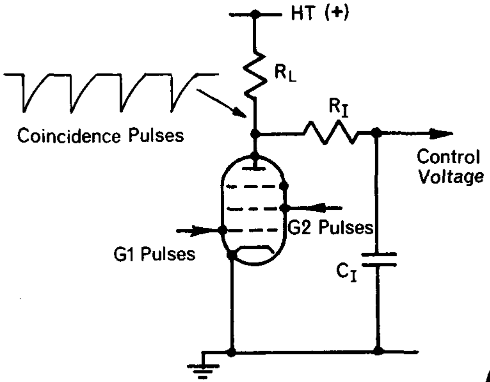


If the frequency of the line sync pulses tends to increase, the leading edges of the G_2 waveform will occur earlier than before, and the G_1 waveform will appear to occur later than before—which corresponds to a *reduction* in the frequency of the line scan oscillator. This has exactly the same effect on the detector circuit as does an increase in the frequency of the line sync pulses. So the two waveforms tend to move further apart in phase, with the leading edges of the G_1 waveform moving further down the lagging edges of the G_2 waveform. The area of coincidence becomes smaller than normal, resulting in a reduction in the duration of anode current flow and in the amplitude and duration of the coincidence pulses produced at the anode.

If, on the other hand, the frequency of the line sync pulses tends to decrease with respect to the frequency of the line scan oscillator, the two waveforms move closer together in phase, and the leading edges of the G_1 waveform move further up the lagging edges of the G_2 waveform. This causes an *increase* in the coincidence area, with a consequent increase in the period of anode current flow and in the amplitude and duration of the coincidence pulses at the anode.

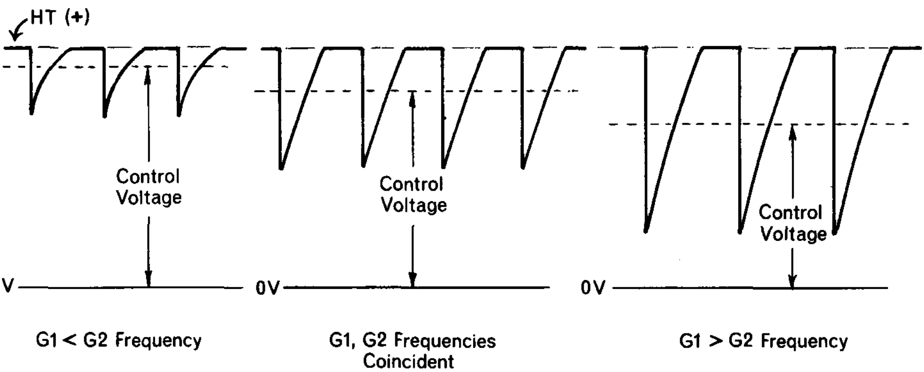
Generating the Control Voltages in the Coincidence Detector

Before the coincidence pulses can be used to control the frequency of the line scan oscillator, they need to be converted into a steady d.c. voltage whose amplitude must vary in accordance with either gradual or sustained variations in the degree of coincidence. This is done by feeding the coincidence pulses into a simple integrator circuit formed by a resistor and capacitor. These components are labelled $R_I C_I$ in the illustration below.



COINCIDENCE DETECTOR

PRODUCING THE CONTROL VOLTAGE IN THE *Coincidence Detector*



When the coincidence pulses are first applied to the integrator circuit, a d.c. voltage gradually builds up across C_I equal to the average value of the coincidence pulses, and proportional to the areas of the individual pulses. (The area of a pulse is equal to the product of its amplitude and its duration.) Provided the frequencies of the G_1 and G_2 waveforms remain the same, this voltage will remain steady—as will therefore the frequency of the line scan oscillator.

Should the frequency of the line sync pulses increase, the areas (and therefore the average value) of the individual coincidence pulses applied to the integrator will become smaller. This will cause an increase in the d.c. level appearing across C_I, and therefore an increase in the controlling voltage applied to the line scan oscillator.

Generating the Control Voltage in the Coincidence Detector *(continued)*

You know that an increase in the control potential causes an increase in the frequency of the oscillator. This, of course, brings about a greater degree of coincidence between the G_1 and G_2 pulses, which in turn causes an increase in the area of the coincidence pulses at the anode of the coincidence detector. The circuit is trying to restore the control potential to what it was before the change in line sync frequency; and eventually, the frequency of the line scan oscillator is adjusted to match the higher frequency of the line sync pulses. The control circuit then becomes quiescent.

The same thing happens, save that the control potential is *decreased* instead of increased, when either the frequency of the line sync pulses is *decreased* or the frequency of the line scan oscillator is *increased.*

The time constant of the integrator circuit ($C_I \times R_I$) is chosen so that it is only capable of responding to slow changes in the shape of the coincidence pulses. It is this deliberate sluggishness of response which makes the circuit insensitive to sudden bursts of noise or interference pulses, or to short-term variations in frequency.

The value of the time constant is fairly critical. If it is made too long, the controlling voltage will be unable to react sufficiently quickly to genuine changes in the frequencies of the line scan oscillator or of the line sync pulses—such as may occur, for instance, when changing channels. If made too short, the circuit will respond too readily to interference pulses, and line tearing will not be prevented.

The Coincidence Detector—Full Circuit Diagram

The illustration opposite shows a coincidence circuit which has found wide acceptance in lower-priced TV receivers. It lacks high sensitivity and to that extent is less effective in operation than are the more complex circuits found in more expensive receivers. The circuit employs a double (triode-pentode) valve, of which the triode section functions as an inverter-amplifier and pulse shaper; and the pentode section as the coincidence detector.

Negative-going line sync pulses from the anode of the sync separator stage are applied to the grid of the triode through a differentiating circuit formed by C_1 and the parallel combination of R_1 and R_2. This circuit produces a pair of negative and positive spikes for each line sync pulse, corresponding to the leading and trailing edges of the pulse respectively.

The resistors R_1 and R_2 form a potential divider across the HT supply, and bias the triode so that its anode current flow is near saturation. Anode voltage is thus nearly "bottomed", as low as it will fall. The positive spikes applied to the grid therefore cause little increase in the already high anode current of the triode, and equally little reduction in the already-low anode voltage. The negative spikes, on the other hand, drive the grid of the valve beyond cut-off, with the result that anode current is momentarily reduced to zero and anode voltage is allowed to rise to the value of the HT supply. Anode voltage remains at this value until the negative voltage of the spike rises to within the grid base of the valve—whereupon anode current once more flows and anode voltage starts to fall.

The value of anode current, and therefore of anode voltage, varies according to the shape of the trailing edge of the negative spike at the grid. Since this is basically exponential, the fall of anode voltage will be exponential also. So every sync pulse applied to the triode produces a single flat-topped positive-going pulse at the anode, this pulse having a sharp leading edge but a sloping trailing edge such as you saw in the illustration two pages back.

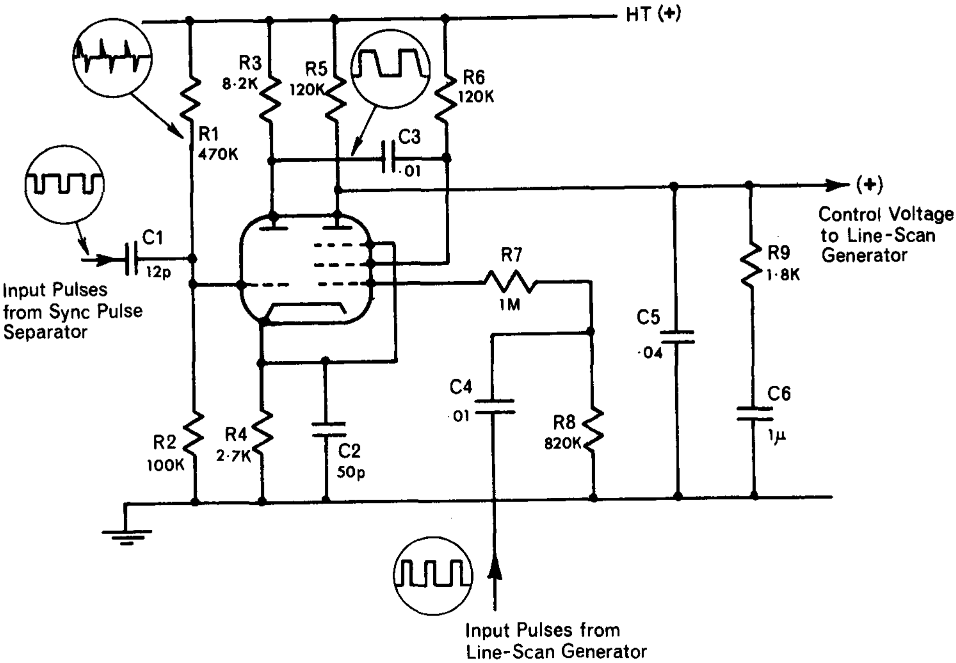
The Coincidence Detector—Full Circuit Diagram

The positive-going pulses produced at the anode of the triode are applied to the screen grid of the pentode via the coupling capacitor C_3. At the same time, positive-going rectangular pulses from the line scan generator are applied to the control grid of the pentode via the long time-constant formed by C_4 and R_8. (The purpose of R_7 is to reduce the effect of amplitude variations in this waveform.)

The pentode thus receives input signals from two sources, and the magnitude and duration of its anode current pulses will vary according to the degree of coincidence between these two signals.

The coincidence pulses produced at the anode of the pentode are smoothed by the integration circuit formed by C_5 and R_5, and a steady positive control potential (for a given degree of coincidence) is developed across C_5.

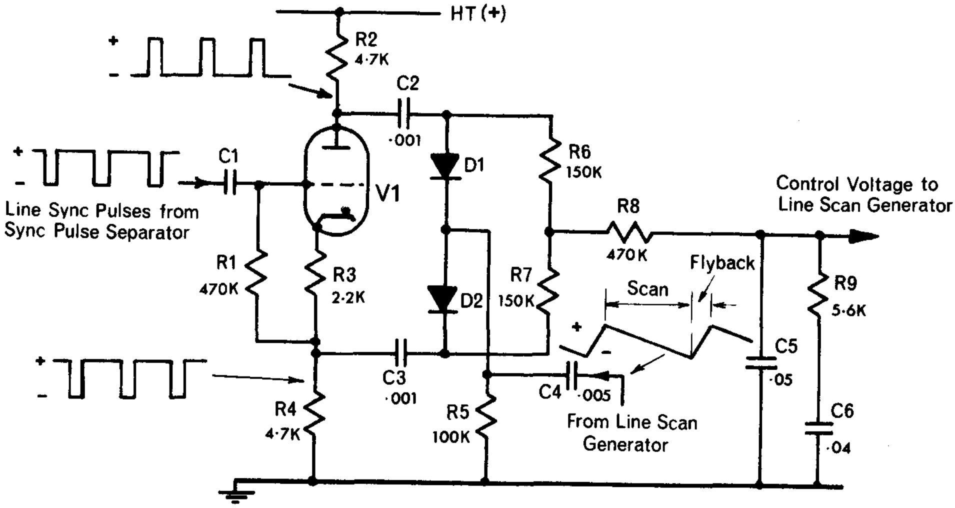
The components R_9, C_6 connected across the control potential line provide low-frequency damping of the circuit, thereby preventing "hunting" by the frequency of the line scan generator. Without them, the frequency of the line scan generator could swing beyond that set by a change in control potential, with the result that it might never quite settle down to its correct value.



Full Circuit Diagram of the
COINCIDENCE DETECTOR

The Phase Detector

The second main type of frequency comparison circuit is the phase detector. Its full circuit diagram is illustrated below.



Full Circuit Diagram of the PHASE DETECTOR

Negative-going sync pulses from the sync separator stage are applied to the grid of V_1. This valve has two load resistors of equal value, one (R_4) in its cathode and the other (R_2) in its anode. R_3 is a cathode biasing resistor, and R_1 the grid resistor. Since the anode and cathode potentials move in opposite directions when a signal is applied to the grid, sync pulses of equal value but opposite polarity will be produced across the anode and cathode load resistors whenever sync pulses are applied to the grid. The valve therefore functions as a phase splitter, in the same way as does a transformer having a centre-tapped secondary winding. Indeed, a transformer is often used in this role instead of a valve or its equivalent transistor.

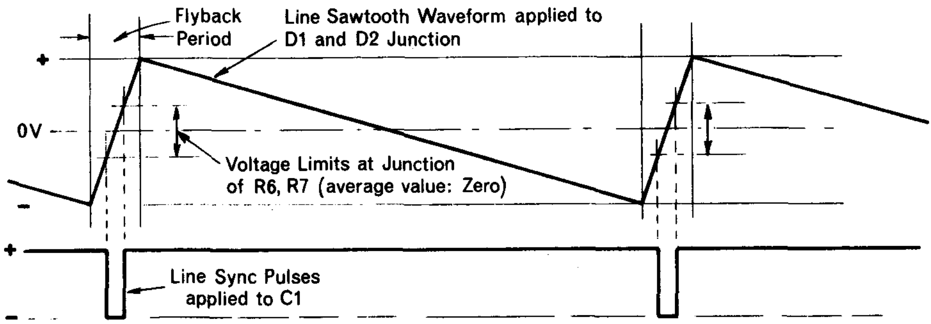
The anti-phase sync pulses from the phase splitter are applied via the capacitors C_2 and C_3 to the opposite ends of two series-connected semiconductor diodes (D_1 and D_2). The positive sync pulses are applied to the anode of D_1 and the negative pulses to the cathode of D_2; both diodes are therefore forward-biased by the sync pulses, and are free to conduct. But a sawtooth waveform from the line scan generator is also applied to the anode–cathode junction of the two diodes, via the *CR* coupling circuit C_4–R_5; and it is the time-phase relationship between this waveform and the anti-phase sync pulses which controls the conduction period of the diodes.

The coupling circuit C_4–R_5 gives the sawtooth waveform equal positive and negative areas above and below a mean base-line value of zero—because C_4 cannot pass a direct current. This means that the anode–cathode junction of the two diodes will be alternatively positive and negative.

The time-phase relationship between the sawtooth and the anti-phase sync pulses is made such that, when the circuit is functioning correctly, the sync pulses occur at the point of time coincident with the centre point of the flyback period, and straddling the zero-voltage base line. This condition will now be considered.

The Phase Detector (*continued*)

The illustration shows the time-phase relationship which exists between the line sync pulses and the sawtooth waveform from the line scan generator in the normal operating condition when the line scan generator is running at the correct frequency.



At the instant when the leading edge of a particular sync pulse occurs, the flyback period of the sawtooth waveform is of negative polarity, rising towards zero (and beyond it). The junction of D_1 and D_2 in the circuit opposite follows this polarity, and at the instant considered is also negative. D_1 is therefore forward-biased by the negative potential on its "cathode" and the positive potential (derived from the sync pulse at the anode of V_1) on its "anode". D_2 is reverse-biased by the sawtooth potential, and is therefore not conducting. With D_1 conducting, C_2 charges up through R_2, D_1 and R_5, its right-hand electrode thus acquiring a negative charge of a value governed by the voltage present at the junction D_1–D_2.

When the flyback period of the sawtooth waveform passes through zero, the junction D_1–D_2 takes up a positive potential, rising towards the maximum value of the sawtooth. D_2 now becomes forward-biased by the positive potential on its "anode" and the negative potential (derived from the sync pulse at V_1 cathode) on its "cathode". D_2 therefore conducts and allows C_3 to charge through R_4, D_2 and R_5 until its right-hand electrode acquires a negative charge equal in magnitude, but opposite in polarity, to that already possessed by C_2. During this time D_1, reverse-biased, is not conducting.

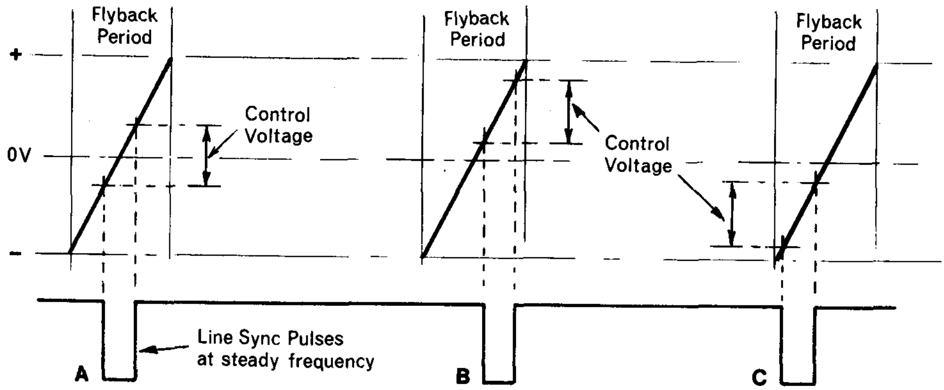
At the end of the duration of the sync pulse (which comes while the sawtooth flyback is still increasing positively), both diodes are non-conductive. They remain in this condition during the scan period of the sawtooth until the next sync pulse arrives—whereupon the whole process is repeated, and C_2 and C_3 replenish the charge which leaked away during the scan period.

This leakage of charge is quite small and takes place through the two equal-value resistors (R_6, R_7) connected in series across the two diodes. Since the remote ends of these two resistors are connected to the right-hand electrodes of C_2 and C_3 respectively, the potentials at these ends will be opposite but equal. The polarity of the voltage at their centre-point connection will therefore be fluctuating about zero. By connecting an integrating circuit (R_8, C_5) to this point, the fluctuations can be smoothed out, and a steady d.c. level (in this case zero) obtained which is used as the control potential for the frequency of the line scan generator.

The time constant of the integration circuit R_8–C_5 is chosen so that it will respond to gradual changes appearing at the junction of R_6 and R_7, but will ignore such short-term variations as may occur between individual sync pulses. C_6 and R_9 are the normal damping components used to prevent "hunting" by the frequency of the line scan generator.

The Phase Detector (*continued*)

Should the frequency of the line scan generator start to rise above that of the incoming line sync pulses, the commencement of its flyback period relative to the commencement of the line sync pulses will appear to occur earlier. Conversely, should the frequency of the generator be reduced, its flyback period will appear to occur relatively later. The illustration shows the time-phase relationship between the line sync pulses and the line scan generator sawtooth for three operating frequencies of the generator: **A**=normal, **B**=higher than normal, and **C**=less than normal.



The *PHASE DISCRIMINATOR:* Control Voltages

Consider Situation **B.** With the flyback period of the sawtooth waveform occurring earlier than normal, the line sync pulses arrive at a time when the flyback is passing through its positive region. Consequently, instead of D_1 and D_2 conducting in turn, only D_2 will now conduct because only it is forward-biased by the flyback voltage appearing at the junction of the two diodes. Only C_3 is now enabled to charge up—and it does so this time to a higher positive voltage than normal because the conduction period of D_2 occurs at a higher point on the flyback waveform.

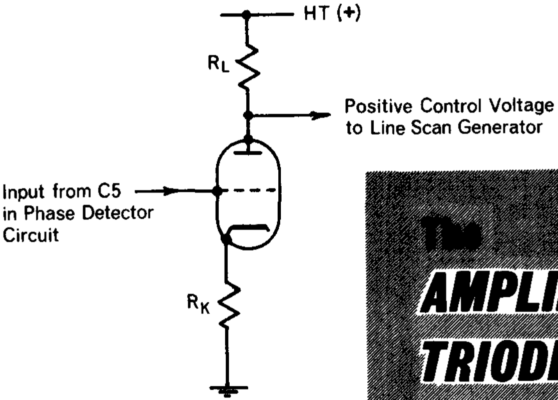
With D_1 not conducting, C_2 cannot replenish the charge it lost during the preceding scan period of the sawtooth waveform and would, if something did not happen to reverse the process, lose even more of its charge on successive scan periods. What happens to prevent this is that the average value of the voltage appearing at the junction R_6–R_7, and therefore across the integrating capacitor C_5, increases above its normal value of zero and is used (in a way you will shortly see) to correct the frequency of the line scan generator by slowing it down to its normal value. As this happens, the conduction periods of both diodes gradually become equal again, and the charges acquired by C_2 and C_3 result in a mean control voltage of zero across C_5.

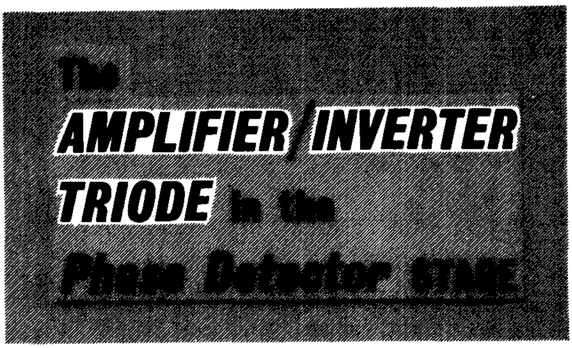
A similar sequence of events takes place when the frequency of the line scan generator falls below normal (Situation **C**). The commencement of the flyback period now appears to occur later than usual, so that the line sync pulses occur during the period when the flyback is wholly negative. Because of this, only D_1 can conduct during the sync pulse periods and only C_2 is able to replenish (and more than replenish) the charge it lost during the preceding scan periods. A negative control voltage is quickly built up across the integrating capacitor C_5 and is used to increase the frequency of the line scan generator until it is again in step with that of the line sync pulses.

The Phase Detector *(continued)*

You have just seen that the controlling voltage developed across the integrating capacitor C_5 is normally zero but that it swings *positive* when the frequency of the line scan generator increases above normal and *negative* when the frequency falls below normal. You know (from the description of the coincidence detector and from earlier discussions on the basic multivibrator) that this is exactly the opposite of the polarities required. Moreover, the swinging of the polarities positive and negative about zero (chassis potential) is quite different from the unidirectional (either wholly positive or wholly negative) polarity actually required.

Both of these difficulties are overcome by connecting into the circuit one more triode in such a way that it functions both as a d.c. amplifier (thereby increasing the sensitivity of the detector itself) and as a signal inverter which also shifts the average d.c. level.





The triode has an undecoupled cathode-bias resistor (R_K) whose purpose is to improve the signal-handling capability of the valve and to reduce distortion. The signal from the integrating capacitor C_5 is applied to the grid of the valve, and the output is taken from its anode. Under normal operating conditions, the input signal is at zero potential, and the valve passes an anode current the magnitude of which is determined by the value of the cathode bias. A steady voltage drop across the anode load resistor (R_L) results, and a positive control voltage is applied to the line scan generator.

Should the frequency of the line scan generator increase, the input signal will become positive and even more anode current will flow. An even greater voltage drop across R_L will cause a *less positive* controlling voltage to be applied to the line scan generator, so reducing its frequency as required. If, on the other hand, the frequency of the line scan generator falls, the input signal to the valve will also fall. Less anode current will flow through R_L; a *more positive* controlling voltage will be applied to the line scan generator, and its frequency will correspondingly increase.

Note that the controlling voltage, although varying in magnitude, remains wholly positive at all times, and that it now always moves in the right direction to control the frequency of the line scan generator.

Pull-in Time

Whatever the nature of the detector circuit used to control their frequency of operation, all timebase circuits require time to settle down to correct synchronisation after signals of a different frequency have been applied to them—as, for instance, when you switch channels on your TV receiver, or when you switch it on "from cold". The length of this *pull-in time*, as it is called, is governed by the sensitivity of the phase detection circuit (the amplitude of the control voltage produced for every degree of phase difference) and by the length of the time-constant of the integration circuit from which the control potential is derived.

Ideally, pull-in time should be as short as possible so that corrections are made to the frequency of the line scan generator as soon as a genuine and sustained difference exists between its frequency and that of the incoming line sync pulses. Unfortunately, however, as pull-in time is made shorter, so the circuit becomes progressively more susceptible to the effects of impulsive interference.

A problem also arises during the period of the field sync pulse when the flywheel circuit receives pulses recurring at twice-normal line pulse frequency (the half-line pulses); for these can upset the operational balance of the circuit. Given a very short pull-in time, however, the circuit will correct itself just as quickly as it became upset as soon as the normal line sync pulses are restored at the end of the field pulse.

If pull-in time is made longer than the duration of the field sync pulse, of course, no problem will arise; for the circuit will be too sluggish in the first place to respond to the "error" presented by the appearance of the half-line pulses. So a long pull-in time is required to make the flywheel circuit insensitive to impulsive interference, and a short pull-in time is required to ensure rapid correction to the frequency of the line scan generator when genuine frequency differences arise.

The length of pull-in time actually built into a given receiver is (as so often in TV design) a matter of compromise. A typical length would be the duration of 20 to 200 lines, though it may be much longer than that in some makes of receiver.

The frequency range within which the flywheel circuit is capable of controlling the line scan generator is called the *pull-in range* of the circuit. A typical operating range, for either line system, would be approximately $\pm 1\%$ about the normal operating frequency of the system.

Some Drawbacks of the Flywheel Sync System

Though the introduction of flywheel sync has undoubtedly improved the overall picture quality of the modern TV receiver, particularly in regions of fringe-area reception, its complexity has certainly added to the cost of the set. And as a large proportion of all TV receivers are used in regions close to the transmitter where reception is generally good and signal-to-noise ratio high, it is not universally accepted in the industry that the extra performance is worth having at the price. No doubt the solution to this particular dilemma will vary in different parts of the world according to whether a critical proportion of potential customers live in areas of generally good, bad or "middling" reception.

Some Drawbacks of the Flywheel Sync System (*continued*)

Two particular faults to which some types of flywheel sync circuit are prone should be mentioned. The first of them manifests itself during switch-on. If for some reason (generally mis-adjustment of the line-hold control) the frequency of the line scan generator is considerably different from that of the incoming line sync pulses, it can happen that the flywheel circuit will be unable to cope with the difference at all. In such circumstances the viewer must alter the frequency of the line scan generator himself by manipulation of the line-hold control, so as to bring the frequency of the generator sufficiently close to that of the line sync pulses for the control voltage to be able to take over and lock the picture by eliminating all frequency difference.

The other problem arises when a picture appears on the picture tube which is perfectly stable but which is displaced horizontally by up to one half-line across the tube. The result is two half-pictures side by side, with the blanking interval positioned between them near the centre of the screen instead of at its ends.

An Effect of PHASE MISALIGNMENT in some Flywheel Sync Circuits

Such a picture can occur in a flywheel sync circuit which compares the frequency of the line scan generator with that of the line sync pulses *directly*, rather than indirectly by measuring their phase relationship. The flywheel circuit is maintaining the frequency of the line scan generator exactly in step with that of the line sync pulses, but the two are out of phase. In other words, the line sync pulses are occurring, in time, halfway along the scan period of the line scan waveform.

The fault is usually caused by incorrect adjustment of the line-hold control, or by incorrect setting of an internal line-phase control. (Indeed, correct initial setting of the line-hold control is considerably more critical in flywheel sync circuits than it is in circuits employing direct synchronisation.)

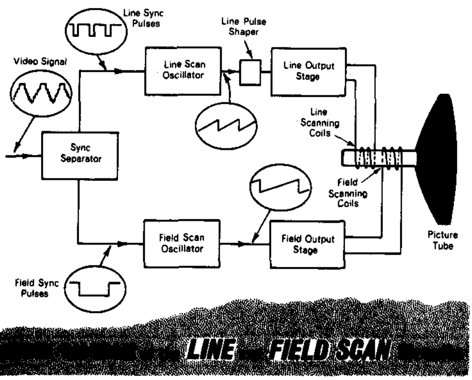
Once correctly set, however, the line-hold control can be adjusted over a considerable part of its range without upsetting synchronisation, functioning rather like a horizontal shift control by means of which the picture can be made to move bodily from left to right, or *vice versa.*

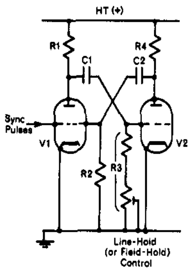
What happens is that the control, being unable to change the frequency of the line scan generator because every adjustment is counteracted by a corresponding change in the control voltage from the flywheel circuit, alters instead the *phase* of the waveform it produces. The effect is obviously to shift the picture bodily towards one side or other of the screen of the picture tube.

REVIEW of the Scanning Generators

The line and field scanning generators produce waveforms which, after subsequent shaping and amplification, are used to control the scanning currents in the line and field scanning coils. These coils are thereby caused to produce the scanning raster on the screen of the picture tube.

The operating frequencies of the two generators are synchronised with those of corresponding circuits in the studio camera by pulses extracted from the video signal in sync pulse separator stage.





$C1.R3 < C2.R2$

The *Asymmetric* Multivibrator

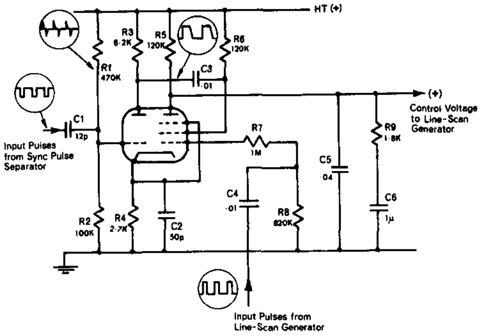
The *multivibrator* makes an inexpensive waveform generator much used in both line and field scan circuits. Its operating frequency is determined by the time constants of two sets of cross-coupled capacitors and their associated grid resistors.

In many TV sets, the operating frequency is controlled by varying the value of one of the two grid resistors. A control of this kind is called a *line hold control* if the circuit is being used to generate line-scan waveforms, and a *field hold control* if it is being used for field-scan waveform generation.

Flywheel synchronisation is a technique employed to keep the line-scan synchronisation consistently stable despite the presence of interfering noise pulses. In the absence of such a technique, the picture could be subjected to *line tearing*.

REVIEW of the Scanning Generators (*continued*)

The coincidence detector is a frequency-comparison circuit much used in flywheel synchronisation. It produces a surge of anode current flow when the frequencies of the line scan oscillator and of the line sync pulses extracted from the incoming video signal coincide, and flows of lesser and lesser value as the two waveforms move further apart in phase. The coincidence pulses produced as a result of these changing anode current flows are used to control the frequency of the line scan oscillator.



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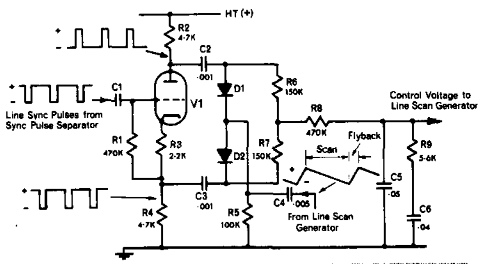


Full Circuit Diagram of the [redacted]

The *phase detector* is a widely used alternative to the coincidence detector. It compares the phase of the pulses produced by the line scan oscillator with that of the line sync pulses extracted from the incoming video signal, and produces an output voltage proportional to the difference. This output pulse is used to control the frequency of the line scan oscillator.

§19: DEVELOPING THE FIELD SCAN

Your next job is to see how the line and field scan waveforms are developed until they are large enough and of the correct shape to activate the line and field scanning coils clustered round the neck of the picture tube. It is best to begin with the field scan waveform, since it is considerably the simpler of the two.

First, a word about the electrical characteristics of the field scanning coils, because these characteristics largely determine the shape of the current waveforms which need to be applied to the coils to produce the shape of scan required across the picture tube. (For reasons which you will see in a moment, this waveform is not the perfectly linear one you would expect, though it is very close to it.)

The field scanning coils of a modern TV receiver consist of two identical coils wound into special shapes and positioned 180° apart (*i.e.*, directly opposite one another) round the neck of the picture tube. The coils are electrically connected in series and have a combined inductance of about 90 mH.

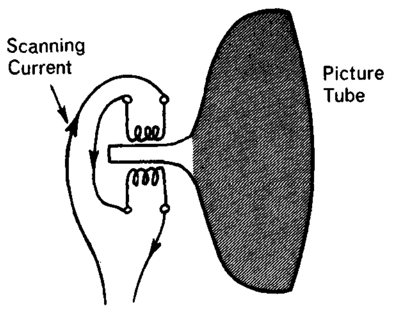
The combined resistance of the coils (caused by the resistance of the fine copper wire from which they are made) is typically about 40 ohms. The coils are supplied from the field output stage with a scanning waveform which has, in all British and European TV systems, a repetition rate of 50 Hz (the field frequency).

You know from *Basic Electricity*, page 3.57, that the inductive reactance, in ohms, of a pair of coils connected in series is given by the equation $X_L = 2\pi fL$, where f is the frequency in Hz and L the inductance in henries. Substituting 0.09 (=90 mH) for L and 50 for f, you get

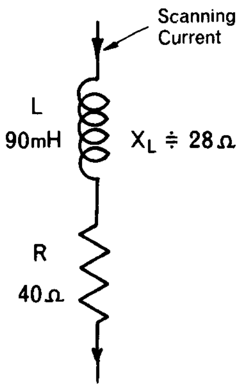
$$X_L = 2 \times 3{\cdot}1416 \times 50 \times 0{\cdot}09 = 28 \text{ ohms (approx.)}$$

Thus the inductive reactance of a typical field scan coil assembly is seen to be rather less than is its resistance. In other words, the coil assembly is *predominantly resistive*, although possessed of a substantial inductive reactance.

Shown below is a bird's-eye view of a basic field scan coil assembly, with its electrically equivalent circuit on the right.



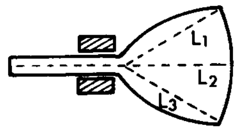
The FIELD SCAN Coils



Equivalent Circuit

The Shape of the Field Scan Waveform

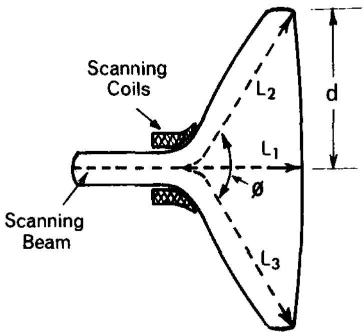
You read on the last page that the shape of the current waveform which needs to be applied to the field scan coils to produce a satisfactory scan down the picture tube is nearly, but not quite, linear.

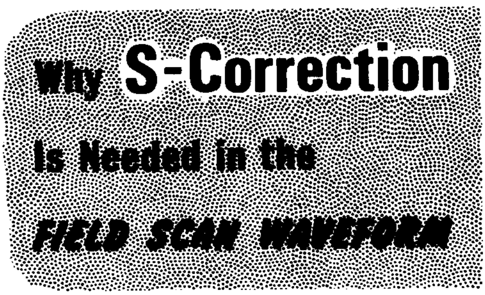


In the earlier TV tubes whose screens were only about 13″ wide and markedly convex (*see diagram opposite*), the length of the scanning beam measured from the centre of the scanning coil assembly was nearly the same whether the beam was at the beginning, middle or end of its scan ($L_1 \doteqdot L_2 \doteqdot L_3$). Given a linearly increasing angular deflection of the beam, therefore, the *rate* at which the beam moved down the face of the tube was pretty well constant.

The requirement, therefore, was for the magnetic field set up by a pair of field scan coils to be linearly related to the magnitude of the scanning current flowing through them—so that a doubling, for example, of the scanning current would double the strength of the magnetic field, which in turn would double the distance travelled by the scanning spot down the face of the picture tube.

The modern picture tube, however, is nearly flat-faced and has a much wider scanning angle—typically 110°. The illustration below shows the sort of difficulty which this introduces.





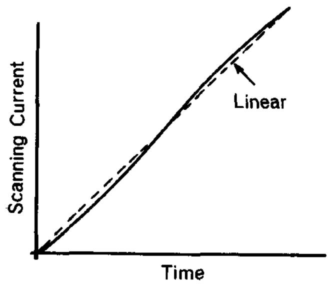
The distance travelled by the scanning spot in traversing half the face of the picture tube is shown as *d*. L_1 is the length of the scanning beam when the spot is moving down the centre of the tube face; L_2 and L_3 its length when the spot is at the beginning and end of the scan respectively. Φ is the scanning angle of the tube. Clearly, both L_2 and L_3 are greater than L_1, which means that the *rate* at which the spot would move down the face of the tube, given a linearly increasing angular deflection of the beam, would be greater at either extremity of the tube face than it would be in the middle.

In other words, the rate at which the spot moves down the face of the tube would be "quick-slow-slow-quick". The result would be that the picture would appear to the viewer to be stretched-out for a few lines at the top and bottom of the picture. Heads would appear egg-shaped, and feet and ankles too long for the legs to which they belonged—rather as in those convex mirrors which face you in the Tunnel of Horrors in seaside amusement arcades. There would also be some decrease in brilliance at these extremities.

The Shape of the Field Scan Waveform (*continued*)

The method adopted to compensate for this effect is to introduce some small degree of curvature into each end of the scanning waveform in order to lessen the velocity of the scanning spot at the beginning and end of the scan. As the scanning waveform increases *at a less-than-linear rate* at the beginning of the scan, so the intensity of the magnetic field produced by the scanning coils at that point increases at a less-than-linear rate also. For the great bulk of the scan period, the rate of increase in current flow through the coils then becomes linear, but it falls off again to less-than-linear as the scan nears the bottom of the screen.

The shape of the field scan waveform required in the modern picture tube thus resembles a much elongated capital letter "S", tilted over at an angle of 45° from the vertical and with all its curves sharply flattened out. The technique is for this reason known as **S-Correction** of the field scan waveform. It is illustrated below.



S-Correction
in the
FIELD SCAN WAVEFORM

You will see in the next Section that S-correction of the waveform is also needed in the line scan, for exactly the same reasons.

The methods used to introduce S-correction vary considerably from receiver to receiver. In the field scan it is generally applied in two stages. The first stage, which affects the initial part of the scanning waveform, relies on the inherent curvature of the I_a/V_g characteristic of the valve used in the field output stage when it is connected to the rather special anode load which you will read about on the next page.

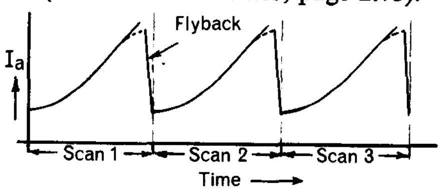
The second stage of correction is applied mostly to the final part of the scanning waveform, and is introduced by a special *RC* network forming part of the Vertical Linearity control, which will also be explained later.

Note that the degree of S-correction needed for the field scan is somewhat less than is that required for the line scan. This is because the *width* of the screen is, as you know, one-and-a-third times greater than its *height* (you will recall that the aspect ratio of the picture is 4:3).

The Field Output Stage

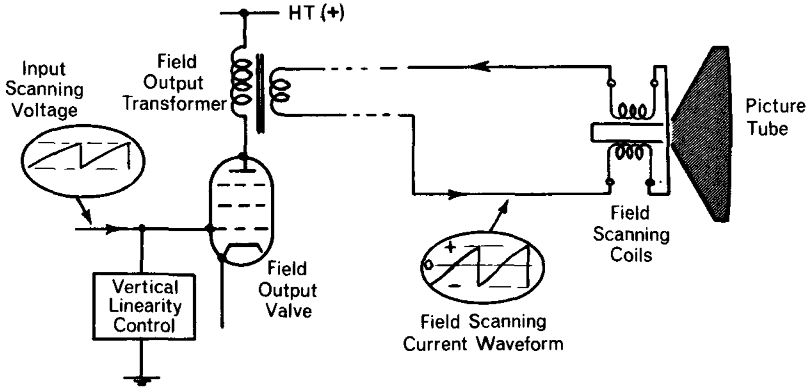
This consists of two elements:— a *power amplifier valve* delivering some 3 or 4 watts of power to the field coils, and an *impedance-matching transformer* connected as the anode load of the valve and serving to couple it to the coils. Both the valve and transformer operate very much as do the PA valve in a radio set and the output transformer which matches it to the loudspeaker (*see Basic Electronics*, page 2.73).

The essential features of the field output stage are shown in the illustration on the next page. Pictured opposite is the shape of current waveform needed at the anode of the valve to produce the S-corrected waveforms in the field scanning coils.



The Field Output Stage (*continued*)

The illustration shows, in outline form, the essential features of the field output stage, together with the voltage waveform received as input from the field scan generator and the current waveform required to be delivered as output to the field scanning coils.



The ESSENTIAL FEATURES of the FIELD OUTPUT STAGE

You have seen that the field scan coils are predominantly resistive but also have substantial inductive reactance. To drive a linearly rising current through such coils requires an applied voltage which contains (*a*) a linearly rising component to overcome the resistance of the coils, and (*b*) a rectangular component to overcome their inductive reactance. Such a composite waveform is a step sawtooth of trapezoidal shape such as was explained in greater detail on pages 2.60 to 2.63 of *Basic Electronic Circuits* (which you would do well to re-read at this point). In the case of the field scan coils of a TV set, as you also know, the step sawtooth requires to be further modified to allow for S-correction of the field scan current waveform.

The required waveform must be derived, of course, from the secondary of the output transformer. This winding, too, will possess both resistance and inductive reactance —as will also its primary, which receives its input from the anode of the PA valve. Thus this valve, "looking into" the primary of the output transformer, sees as its anode load an impedance composed of certain values of resistance and inductive reactance derived from the characteristics of two stages—the transformer itself and the load connected to its secondary (*i.e.*, the scanning coils). Given the types of scanning coil and output transformer used in a modern TV receiver having a wide-angle picture tube, the effective anode load of the PA valve possesses an impedance such that the waveform of current flowing in the primary of the output transformer—which is also the anode current of the valve—must have a shape like that pictured at the foot of the last page.

This shape is called *parabolic*, and the waveform is said to have *zero initial slope.* This zero initial slope assists in providing the required S-correction for the *beginning* of the scan. You will shortly see how S-correction for the *end* of the scan is provided by the Vertical Linearity control circuit which alters the shape of the input voltage waveform applied to the grid of the valve.

The Field Output Stage *(continued)*

The full circuit diagram of a practical field output stage is shown in the illustration opposite.

The grid bias of the output valve (V_1) is determined by the cathode bias components C_3 and R_3, whose values are carefully chosen to give the correct operating point and to ensure the correct shape of anode current waveform. The peak-to-peak value of anode current required for the full vertical scan of a 19″ picture tube is about 100 mA, which corresponds to a peak-to-peak current of some 500 mA flowing through the field scan coils.

The output transformer (T_1) has a primary-to-secondary turns ratio of about 5:1, and is connected to the field scan coils through the thermistor R_x. A *thermistor* is a temperature-sensitive resistor made from a carbon composition whose resistance becomes *less* as its temperature increases. It is thus said to have a negative temperature coefficient of resistance.

The resistance of R_x at normal room temperature (about 25°C) is 8 ohms, and the resistance of the field coils at the same temperature is, as you know, some 40 ohmns. Since the resistance of the secondary winding of the output transformer is about 15 ohms, the total resistance in the secondary circuit, at 25°C, is about $8+40+15=63$ ohms.

When the TV receiver has been running for some time, the temperature inside the cabinet will have risen considerably and will have affected the resistance of the transformer secondary and of the scanning coils. Since these are both wound from copper wire which has a *positive* temperature coefficient of resistance, their individual resistances *increase* as the set warms up. This increase in resistance, unless counteracted, would cause a reduction in the magnitude of the scanning current and a shrinkage in picture size. But the thermistor is also affected by heat—only as the temperature rises, its resistance *decreases*. So if its value is chosen to be such that its resistance decreases by approximately the same amount (within a limited temperature range) as the resistance of the other two components rises, the overall resistance of the secondary circuit will be maintained constant at about 63 ohms.

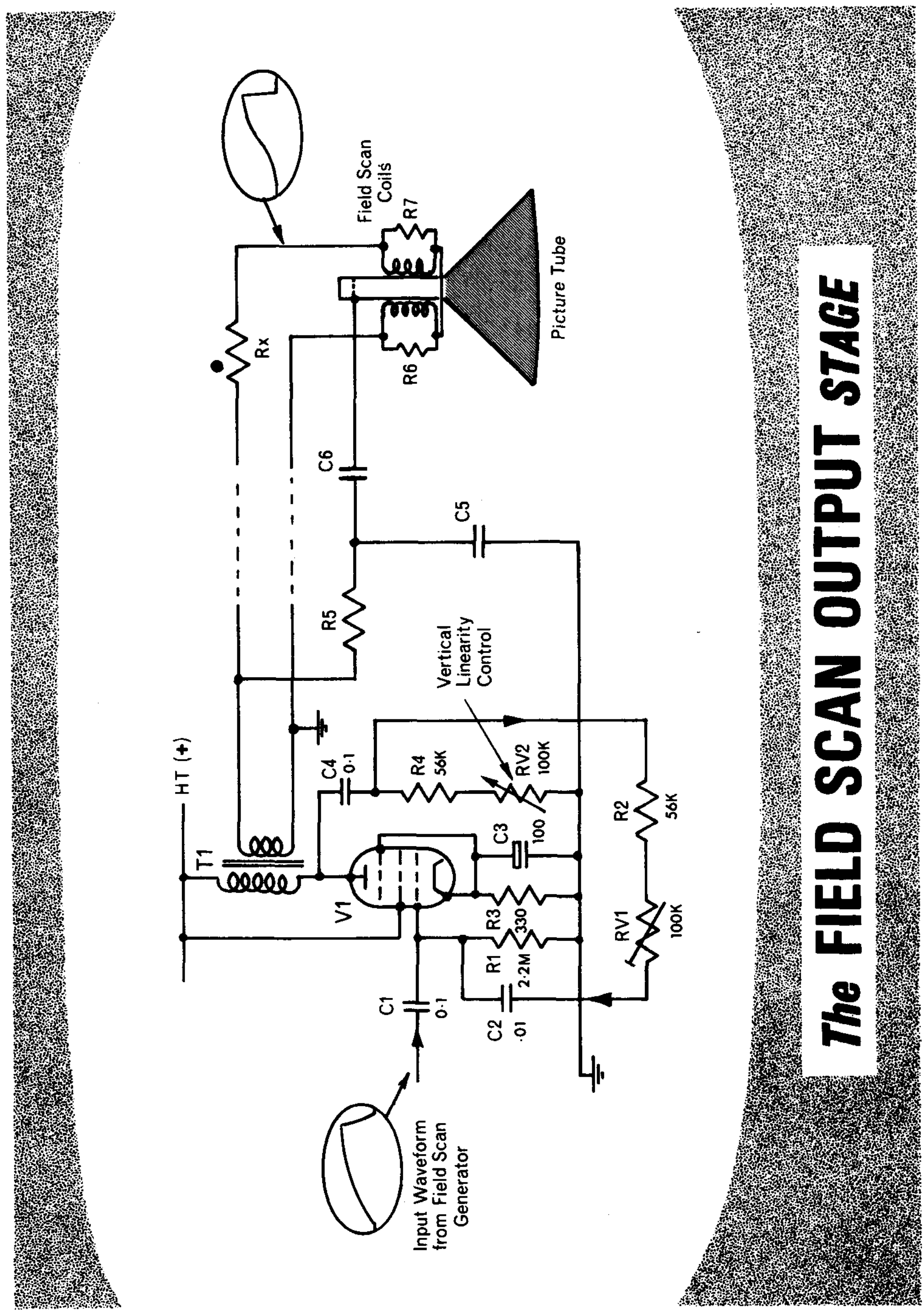
The incoming signal from the field scan generator (which you know to be of exponential sawtooth shape) is coupled to the grid of the output valve via C_1, and is developed across the grid leak resistor R_1. After amplification, it appears in the normal way at the anode of the valve, where it is developed across the primary of the output transformer and applied to the scanning coils.

Vertical Linearity and S-Correction

The waveform at the anode of the PA valve also appears across C_4, R_4 and RV_2. Together with R_2, RV_1, C_2 and R_1, these components form the Vertical Linearity control shown in block outline in the illustration on the last page. C_4, R_4 and the adjustable RV_2 enable the shape of the waveform developed across R_1 to be varied by filtering out some of the harmonic frequencies contained in the waveform at the anode. The filtered waveform is then fed back to the grid of the valve, in opposite phase to the incoming signal, via R_2, RV_1 and C_2.

The actual amount of current so fed back is controlled by the setting of RV_1 (which also influences the shape of the waveform). This method of linearity correction operates by feeding back a negative waveform such that the shape of the input waveform appearing at the grid of the valve (*i.e.*, across R_1) is distorted so as to produce a waveform of current in the field scan coils which possesses the required amount of S-correction over the last 30 lines or so of the scan.

The Field Output Stage (*continued*)



The FIELD SCAN OUTPUT STAGE

The Field Output Stage (*continued*)

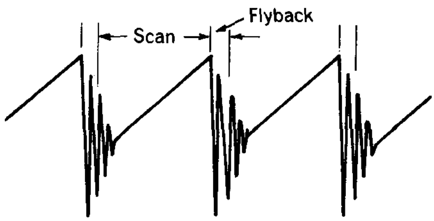
In a practical receiver, RV_2 would be a viewer-operated control labelled *Vertical Linearity* on the outside of the set. It would be used to correct the picture if the leading lady started to develop that Hall-of-Mirrors effect in head or feet! RV_1 would be mounted within the set and normally preset at the factory so as to produce, in conjunction with RV_2, the required linear scan. It should require further adjustment only to compensate for ageing of the output valve.

The components R_5, C_5 and C_6 form a flyback-suppression circuit which helps to prevent the field flyback lines from becoming visible on the picture tube when the viewer adjusts his *Brilliance* control for a brighter-than-usual picture. (You saw on page 1.74 the type of line pattern you might otherwise get superimposed on the normal picture.) R_5 and C_5 form a potential divider across the secondary of the output transformer, and C_6 couples the voltage developed across C_5 to the grid electrode of the picture tube. The reactance of C_6 to the comparatively slow rise of the scanning waveform is high, so little voltage is fed to the picture tube during this period. At the end of the scan, however, the current in the field coils is rapidly reduced. The resistance of C_6 to the sharpsided flyback waveform appearing across C_5 is very low, and a large negative pulse is applied to the grid of the picture tube sufficient to black-out the scanning beam during the flyback period.

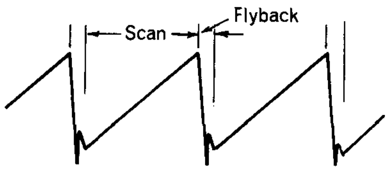
It should be noted that not all receivers employ this type of flyback suppression circuit. Some derive the necessary negative pulses from the scanning generator itself.

The two resistors R_6, R_7 shown connected across the field scan coils belong more logically to the picture tube stage; but because their equivalent components in the line scan circuitry play an important part in the line output stage, it will be convenient to cover their function and mode of operation at this point.

The purpose of R_6 and R_7 is to damp down the ringing oscillation which would otherwise occur across the coils every time the current flowing through them is rapidly reversed during the flyback period. If this ringing were not suppressed, there could be distortion of the picture at the start of every new field—especially if the ringing persisted after the cessation of the flyback period.



UNDAMPED RINGING
(No Damping Resistors)



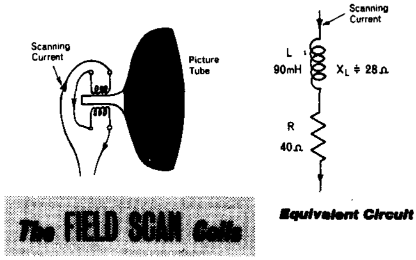
DAMPED RINGING
(With Damping Resistors)

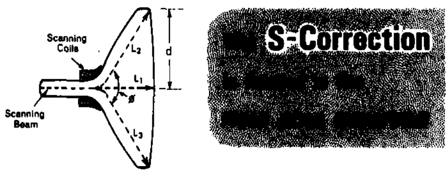
Another dangerous possibility if ringing were not suppressed would be the injection of an interference signal into the line scan coils, which are mounted in very close proximity to the field coils.

In addition to damping down ringing oscillations, R_6 and R_7 serve also to absorb any unwanted pulses which could be injected into the field scan coils from the line coils close beside them. This mutual interference between the line and field scanning coils is called *cross-talk*. It is caused by the stray capacitances and mutual inductance which exist between the two sets of coils. Its effect on the picture is apt to be a fixed pattern of wavy striations running horizontally across the whole screen.

REVIEW of Field Scan Development

The two scanning coils used for producing the field scan are predominantly resistive in nature, though they also possess substantial inductive reactance. The coils are usually connected in series with one another. They form part of the line and field scanning coil assembly situated around the neck of the picture tube.

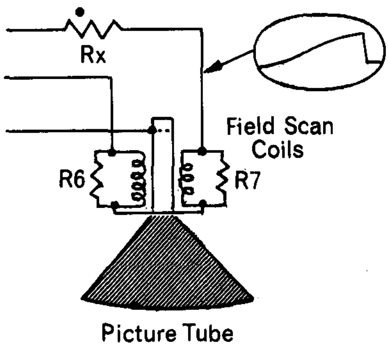




The shape of the scanning current waveform supplied to the scanning coils from the field output stage resembles an elongated and much flattened letter "S". Such a shape of current waveform helps to compensate for the differences in distance which the beam has to travel when scanning the centre, and the top and bottom areas respectively, of the screen. This does much to ensure a properly proportioned picture.

Variations in the resistance of the scanning coils are temperature-compensated with the aid of a series-connected thermistor, selected to have a temperature coefficient of resistance which matches that of the scanning coils, but is of opposite sign.

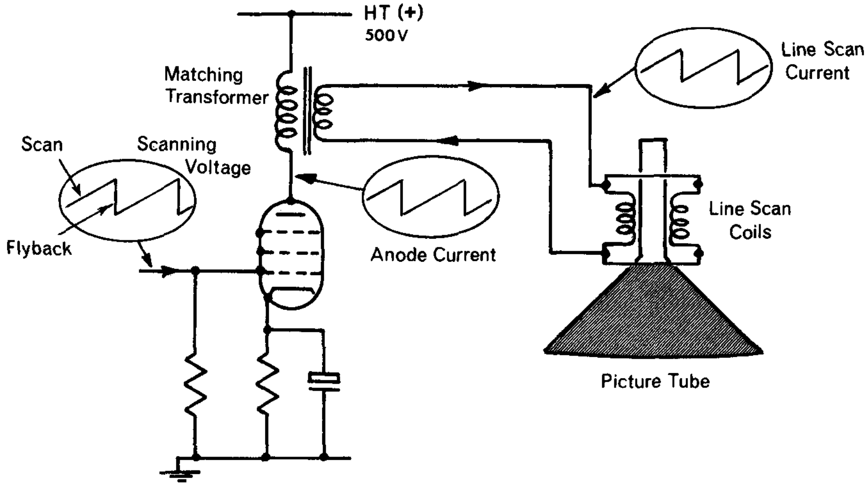
The compensation provided in this way prevents the height of the picture from being affected by changes in temperature which occur within the receiver.



§20: DEVELOPING THE LINE SCAN

The function and basic layout of the line output stage is similar to that of the field output stage. In its simplest form, it too consists of a *power amplifier* valve with an impedance-matching *output transformer* in its anode circuit coupling the valve to the line scan coils.

In practice, however, the line output stage is also required to fulfil two other important tasks. One of these is to produce a "boost" voltage of some 500 to 800 V to be used by the line output valve for its own HT supply—and also (as you will see) by the first-anode electrode of the picture tube. The second task is to produce an EHT voltage supply as high as (typically) 18 kV for the picture tube. Not unnaturally, these two high-voltage requirements introduce complications into the basic circuit of the line output stage; but it is still worth while looking at the latter in outline form as a first step.



The LINE SCAN OUTPUT STAGE—Basic Circuit

The valve is supplied from the line scan generator with a sawtooth voltage which causes a current of similar shape to flow through the primary of the matching transformer, connected as the anode load of the valve. The secondary of the transformer couples the valve to the scanning coils so that, during the "scan" period of the input waveform, the beam of the picture tube carries out a linear scan of the screen. At the end of the scan period of the input voltage, anode current in the valve is reduced to a minimum, the scanning current in the coils is reversed, and the scanning beam is rapidly returned to the left-hand side of the picture tube.

Note that at all times the magnitude of the anode current flowing in the valve, and therefore of the scanning current in the coils, is under the control of the input voltage sawtooth, exactly as were the corresponding current flows in the field output stage.

The Line Scan Coils

The line scan coils are essentially similar to the field scan coils, though they are arranged to have considerably different values of combined inductance and resistance. As you know, the two pairs of coils are clamped together to form a single assembly round the neck of the tube. If they could be viewed through the front of the picture tube, the line coils would be above and below the neck of the tube, with the field coils on either side.

The line coils may be connected either in series or in parallel, but present-day practice tends to favour the parallel connection because it demands fewer associated components.

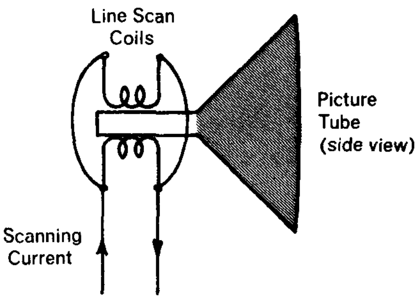
The combined inductance of a pair of line scan coils is generally made much lower than that of a pair of field coils in order to reduce the ringing oscillations which arise in the line coils (and, as you will see, in some other coils in the output stage also) when the onset of line flyback sets up large back-e.m.f.'s across the coils. Because of the very short line flyback period, such oscillations would, if left to themselves, have insufficient time to die away before the initiation of the next line scan. They would resonate with the self-capacitance of the scanning coils, and would produce a series of alternately bright and dark horizontal striations down the left-hand side of the picture.

Typical values of combined inductance and resistance in a line scan coil assembly are therefore made as low as 3 mH and 4 ohms, respectively. You know that the scanning waveform has a repetition rate of 10·125 kHz (in the 405-line system) and of 15·625 kHz (in the 625-line system). So, using again the formula $X_L = 2\pi fL$, you get inductive reactances for the coil assembly as follows:

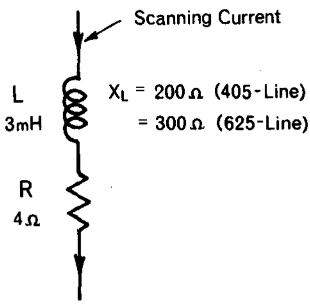
405-line system $2 \times 3{\cdot}1416 \times 10{\cdot}125 \times 10^3 \times 3 \times 10^{-3}$ ohms
$\therefore X_L \doteqdot$ **200 ohms**

625-line system $2 \times 3{\cdot}1416 \times 15{\cdot}625 \times 10^3 \times 3 \times 10^{-3}$ ohms
$\therefore X_L \doteqdot$ **300 ohms**

The inductive reactance of the line scan coils is thus about 60 times the value of their d.c. resistance—a far greater difference than in the field scan coils. The line coils are therefore *predominantly inductive*, and much more strongly so than the field coils are predominantly resistive.



The LINE SCAN COILS



Equivalent Circuit

The Line Output Stage

If a line scan coil assembly with parallel-connected coils, an effective inductance of 3 mH and a d.c. resistance of 4 ohms were to be used in a basic circuit for scanning a modern 19″ picture tube, a peak-to-peak scanning current of about 1·5 amperes would be required. Since the coils are fed from a transformer—which cannot transfer d.c.—the peak-to-peak value of the required scanning current would extend from −0·75 A to +0·75 A, and its average value would be zero.

Now when a *changing* current is passed through any inductor, there is developed across that inductor a back-e.m.f. whose polarity is opposite to that of the voltage which is driving the current through the coils (*Basic Electricity*, page 5.50). The magnitude of this e.m.f. (V_L) is proportional to the value of the inductance (L) and to the *rate* at which the current through the coil is changing. It can be quantified by using the formula:—

V_L (in volts) = L (in henries) × the rate of change of current flow (in amperes per second).

You know from page 1.71 that the duration of the line period in the British 625-line scan waveform is about 52 μs (after allowing some 12 μs for completion of the flyback). During this period, the current in the scanning coils is increasingly *linearly* through a maximum of 1·5 amperes; the rate of change of current flow is therefore $1{\cdot}5 \div 52 \times 10^{-6}$ A/s. Using the formula in the last paragraph, the back-e.m.f. developed across the coils during the scan period is found to be:

$$V_L = 3 \times 10^{-3} \times \frac{1{\cdot}5}{52 \times 10^{-6}} = \mathbf{86\ V}$$

Note that since the scanning current increases linearly (as it should do to produce a linear scan), its *rate of change* will be constant throughout the entire scan period—which means that V_L will also be constant over the same period, at 86 V.

During the flyback period, however, the back-e.m.f. developed across the coils becomes much greater because of the much higher rate of change of current (remember that the scanning current *falls* through 1·5 amperes in a period of only 12 μs). Using the formula again, you get:

$$V_L = 3 \times 10^{-3} \times \frac{1{\cdot}5}{12 \times 10^{-6}} = \mathbf{375\ V}$$

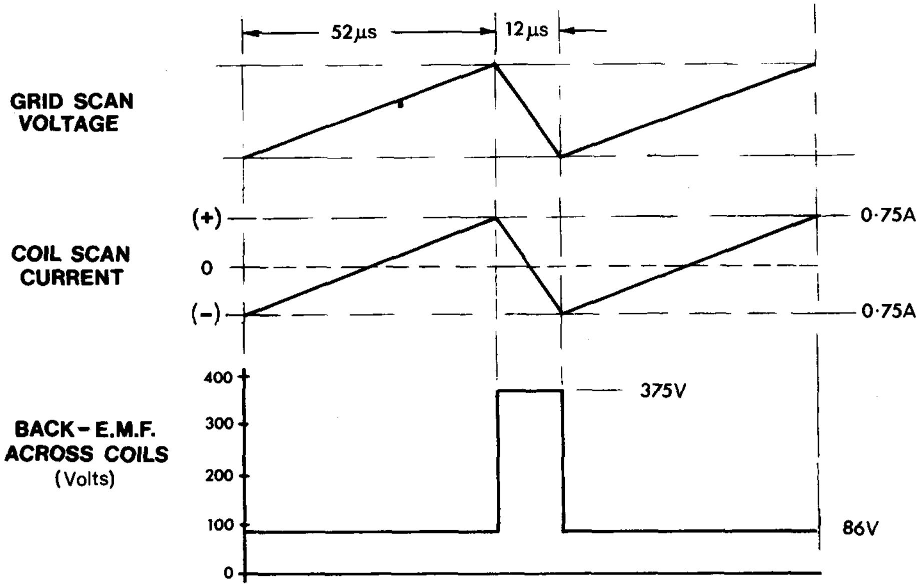
If the fall of current during the flyback period were strictly linear (which in practice is not always the case), the value of V_L throughout flyback would remain constant at 375 V. This is shown in the illustration on the next page, which demonstrates the relationship between the scanning voltage waveform applied to the grid of the line output valve in the basic circuit and the voltage and current waveforms which subsequently appear at the coils.

The voltage developed across the resistive component of the scanning coils (4 ohms) increases linearly during the scan period of the waveform, and decreases in a similar manner during the flyback. The magnitude of this voltage (V_R) may be determined at any moment during the period of the waveform by application of Ohm's law, multiplying the value of the scanning current at the chosen moment (I_s) by the resistance of the coils. Thus, $V_R = I_s \times R$.

Since the peak-to-peak value of the scanning current is 1·5 A, the corresponding peak-to-peak value of V_R will be $1{\cdot}5 \times 4 = 6$ V. This voltage is so small compared to that which is developed across the inductive component of the coils that it can for most practical purposes be ignored.

The Line Output Stage (*continued*)

The illustration below pictures the relationship which exists between the waveforms of voltage applied to the grid of the line PA valve, and of voltage and current which then appear at the line scan coils.



The back-e.m.f.'s which are developed across the scanning coils during the scan and flyback periods also appear, of course, across the secondary winding of the output transformer which feeds them. Since the turns ratio of this transformer is typically 4:1, any voltage appearing across the secondary will appear across the primary *four times as great* (assuming, theoretically, that both coils and transformer are free of both resistance and capacitance).

Thus, if 86 V is developed across the secondary during the scan period, $4 \times 86 = \mathbf{344}$ **V** will appear across the primary during the same period. And if 375 V is developed across the secondary during the flyback period, $4 \times 375 = \mathbf{1{,}500}$ **V** will appear across the primary. This is a very considerable voltage.

But you must also consider what happens to the voltage at the anode of the line output (or PA) valve. During the scan period, the valve is passing anode current, so its anode voltage will be equal to the HT voltage (in this case 500 V) *less* the reflected voltage appearing across the primary of the transformer which forms its anode load. Effective anode voltage during the scan period is therefore $500 - 344 = 156$ V. This is a fairly modest value; but during the flyback period anode current flow in the valve is rapidly reduced to zero and its anode voltage rises until it equals the HT voltage *plus* the reflected voltage (which is now of opposite polarity to that produced during the scan). Effective anode voltage is therefore $500 + 1{,}500$—or the even more formidable figure of 2 kV.

The need to handle these high voltages clearly calls for major adaptations to the basic circuit of the line output stage, and helps to explain why the stage itself presents more problems than did the field output stage examined in the last Section.

The Line Output Stage (*continued*)

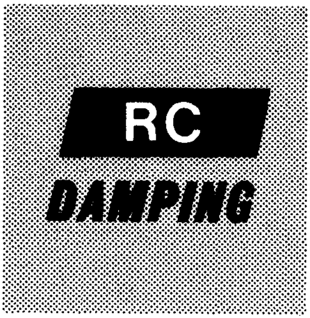
You were assumed to be dealing on the last page with a circuit in which resistance and self-capacitance in the scanning coils and in the output transformer were both non-existent. In practice, of course, both components always possess significant amounts of each, and you must now see how their presence affects the performance of the stage.

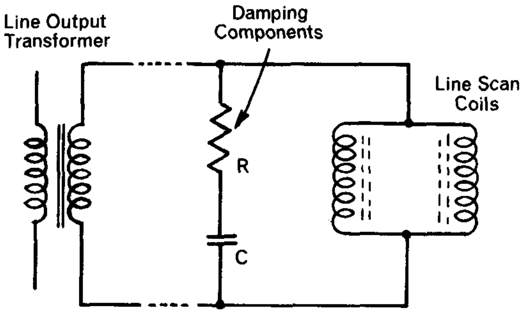
Of the two characteristics, the self-capacitance is the more important, because it reacts with the natural inductance of the circuit to form a tuned circuit.

At the beginning of the flyback period of the scanning waveform, anode current flowing in the tuned circuit from the line output valve is suddenly reduced to zero. This rapid change of current gives rise to the formidable back-e.m.f. already discussed, and it also causes the tuned circuit to resonate at its own natural frequency—which may be anywhere between 20 and 60 kHz depending on the physical construction of the transformer and the coils. This ringing, once initiated, will die away at a rate governed by the resistive losses of the circuit, which consist of the winding resistances of the transformer and coils. The lower the resistance (and therefore the greater the efficiency) of the circuit, the greater will be the time taken for the ringing to die away. In a modern TV receiver of efficient design, it would persist well beyond the flyback period, so impairing the start of the scan period and distorting the picture at the beginning of each new line.

You will recall that when a similar situation arose in the field output stage, ringing was reduced to an acceptable level by the addition of damping resistors across the coils. In the line output stage, where very large voltages are involved, this method of damping is unacceptably inefficient because the resistors would absorb too much energy from the scanning waveform during the period of the scan itself. (You can get an idea of the quantity of energy wasted from the fact that a damping resistor dissipated more than 5 watts of power in the scanning circuits of even the small 9″ picture tube used in very early TV receivers.) Something much better is obviously required for a modern receiver using 23″ picture tubes.

Some improvement in efficiency could be brought about by connecting a capacitor of carefully chosen value in series with the resistor. The reactance of this capacitor would appear large to the slowly rising scan portion of the scanning waveform, so reducing the amount of current absorbed by the damping resistor, but very low to the much faster flyback portion of the waveform. The damping resistor would therefore be able to exert maximum effect.

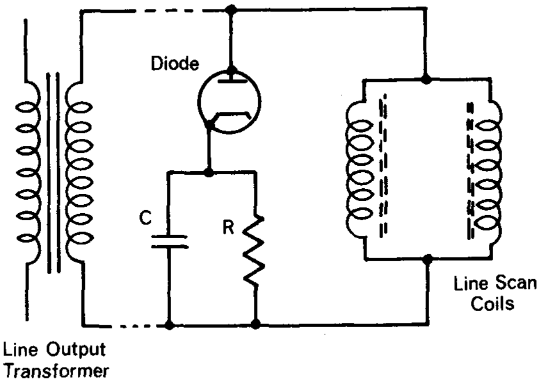


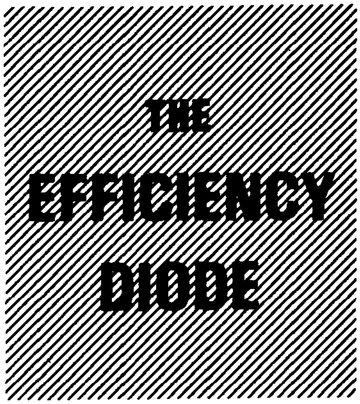


Though better than the single resistor, this method of damping is still not good enough for modern TV circuits, where something much more efficient is required.

The Efficiency Diode

A simple but efficient method of controlling the flyback-generated oscillations in the line output stage is to connect across the line scan coil circuit a diode in series with a parallel *RC* circuit. This arrangement can also be made to play a useful additional role in helping to produce the line scan itself—as will be seen from the illustration below.





When the beginning of the flyback causes the powerful back-e.m.f. across the line scan coils (it is, you will recall, positive-going), the sudden burst of energy which would otherwise have appeared as a ringing oscillation causes the diode to become forward-biased. Its anode conducts, and the energy of the oscillations is stored in the capacitor *C* in its cathode circuit.

The diode continues to conduct for some time after flyback has been completed. While it does so, the anode current flowing in the scanning coils is used to produce the first half (or thereabouts) of the scan itself. It is only when *C* has given up its charge, and the diode has ceased to conduct, that the line output valve takes over and supplies the energy required for the second half of the scan.

It is because of its performance in this double role (first, providing "emergency storage" for unwanted energy and then putting this energy to good use) that the diode, so connected, is often known as the *efficiency diode.*

The Line Output Valve Operated as a Switch

The presence in the circuit of an efficiency diode makes possible a different method of operating the PA valve which greatly reduces the amount of power dissipated within the valve when it is conducting, and so makes it a more efficient power amplifier with a longer useful life.

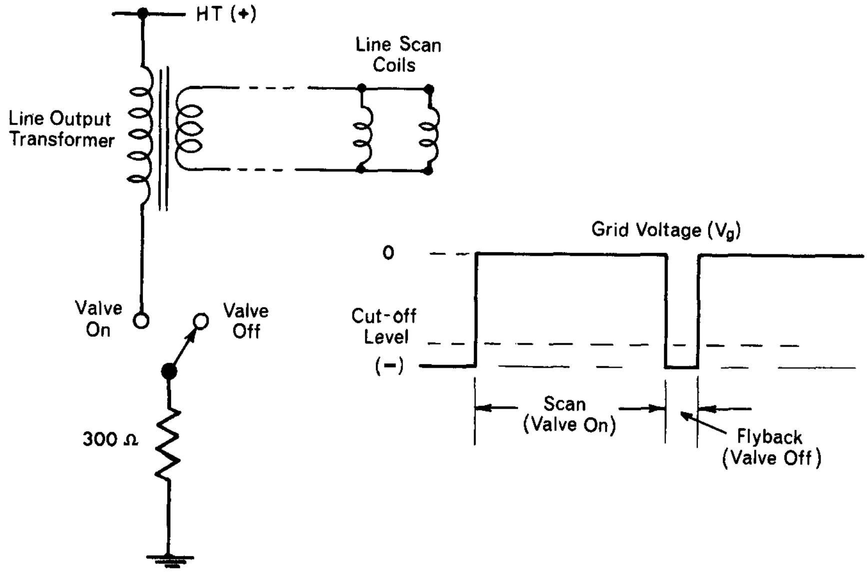
It has been assumed hitherto that the line output valve is required to operate as a Class A amplifier (*Basic Electronics*, page 2.29) in which anode current flows during the whole cycle of the input signal. With the addition of the efficiency diode, this is no longer necessary. A waveform capable of giving a good linear scan can be produced when the output valve itself is only conducting for the short period of some 25 μs constituting the second half of each line scan.

This means that the valve can effectively be operated as a mere electronic switch, with great resultant saving of power loss. You should now see how this is done.

The Line Output Valve Operated as a Switch (*continued*)

When a valve is operated as an electronic switch, it has two states only. It is either cut-off altogether when the switch is "open", or it is conducting heavily at saturation point when the switch is "closed". The sort of waveform which needs to be applied to the control grid of the valve to achieve this kind of operation is obviously rectangular in shape, and extending in amplitude from a value near zero volts when the valve is conducting, to a negative value beyond cut-off when it is not.

The highly simplified illustration below may make it easier to understand how a linear scanning current can be produced by operating the line output valve, not as a power amplifier at all, but as a simple electronic switch.



The LINE OUTPUT VALVE Operated as a SWITCH

When the waveform at the grid rises through cut-off to zero, anode current in the valve builds up and anode voltage quickly falls to saturation value, which is a few volts above zero. When this happens, the primary of the output transformer in the anode circuit of the valve is placed, through the valve, across the HT supply. The current which thus flows in the transformer, and therefore in the scanning coils, builds up at a constant rate and gives a linear scan of the picture tube.

At the end of the scanning period, the grid waveform is again reduced to a value below cut-off and the current in the transformer is reduced to zero.

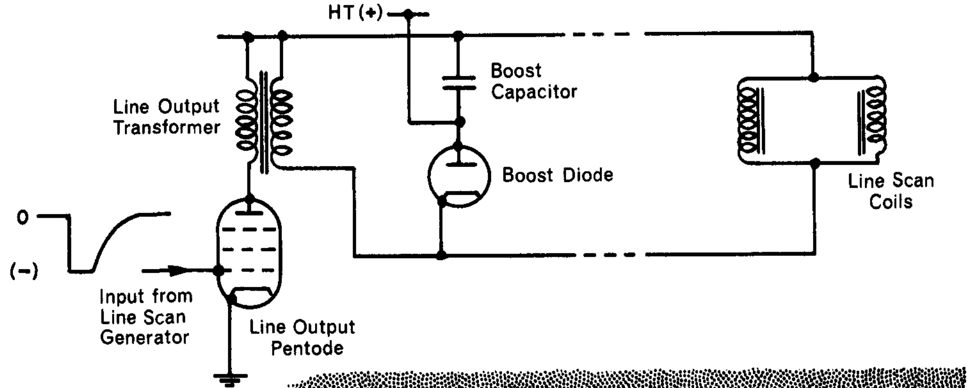
When an efficiency diode is connected in a circuit in which the line output valve is operated as a switch, the two valves conduct in sequence and each makes a contribution to the scan. The valves are in effect operating in a manner analogous to two parallel-connected switches, one being closed while the other is open.

The Boost Diode

There is another, and probably more widely used, way of connecting the efficiency diode so that, instead of acting in parallel with the line output valve, it acts *in series* with it.

In this mode of connection, the energy received by the diode from the ringing oscillation during flyback is still used to charge up a capacitor (typically of some 0·1 μF in value); but now the voltage built up across the capacitor during flyback is connected in series with the HT supply to the line output valve, so boosting the anode voltage of the valve by as much as 250–650 V. Once again, the energy contained in the unwanted oscillations of the line output transformer is put to good use; and it is not surprising that an efficiency diode connected in this way is known as a *boost diode.*

The basic arrangement of such a circuit is shown below, and its associated wave-forms in the illustration overleaf. Briefly, the circuit works as follows.



THE BASIC BOOST DIODE CIRCUIT

At the moment when the latter part of the scan is being produced, the line output valve is conducting heavily and the diode is cut off. Anode current flowing in the pentode, and thus in the transformer primary, is rising linearly towards its maximum value reached at the end of the scan—the current being drawn as a discharge current from the boost capacitor connected in series with the HT supply and the transformer primary.

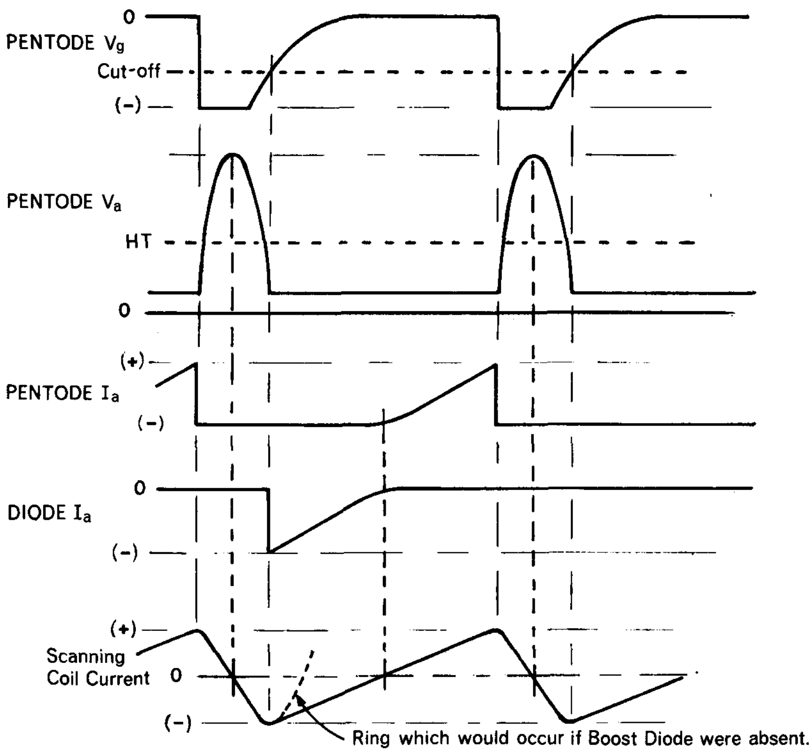
At the end of the scan the pentode is cut off by its grid waveform, and its anode voltage is suddenly driven to a large value by the creation of the back-e.m.f. which results. After this rise has reached its maximum value, anode voltage swings negatively in the opposite direction and starts the first half-cycle of a ringing oscillation. This negative excursion makes the cathode of the diode negative with respect to its anode (the latter being held steady at HT value); and at the peak of the oscillation, the diode conducts.

As it does so, diode current re-charges the boost capacitor. At the same time it also causes the scanning beam to start to move towards the right-hand side of the screen, because the diode current is flowing also through the secondary of the transformer, and so through the scanning coils connected to it. When the boost capacitor has become fully charged, current in the diode ceases to flow and its contribution to generating the line scan ceases simultaneously.

The Boost Diode (*continued*)

During the period when the diode is conducting, the pentode is held below cut-off by the negative portion of the waveform applied to its grid. But the trailing edge of this waveform is deliberately shaped so that, as it rises towards zero, it reaches the cut-on point of the pentode *just before the diode ceases to conduct.* In this way a smooth transition from diode to pentode conduction takes place, the linearity of the scan being unaffected by the change in the agency by which it is produced. The effect will be clearly seen by studying the I_a curves of the pentode and of the diode (waveforms 3 and 4 below).

When the pentode begins to conduct, it once more draws its anode current from the boost capacitor, and the cycle of operation is repeated.



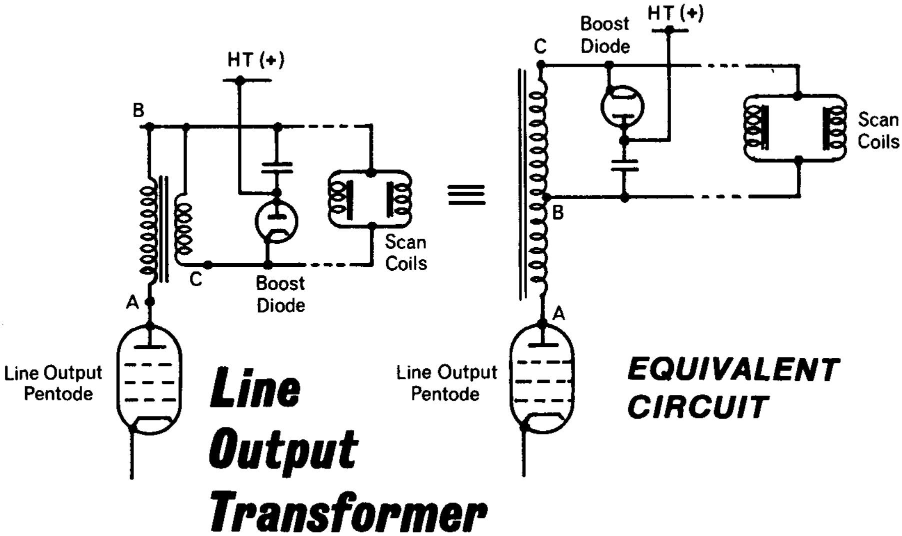
BOOST DIODE CIRCUIT WAVEFORMS

The point to grasp is that the first half of the scan is produced by the anode current of the diode and the second half by the anode current of the pentode. By reason of inevitable losses in the circuit as a whole, the proportions are modified in practice so that the pentode usually produces about 60% of the scan, with only the first 40% being produced by the diode.

Nevertheless, with even 40% of the scan being derived with its aid from an unwanted and potentially tiresome ringing oscillation, it is easy to see how a boost diode adds to the overall efficiency of the line scan circuit.

The Auto-transformer

You may have noticed in the illustration two pages back that one end of the primary winding of the line output transformer is shown as being directly connected to one end of the secondary winding. This means, of course, that complete isolation between the two windings no longer exists, and that the transformer is operating as an auto-transformer (*Basic Electricity*, page 4.80). You will find this easier to appreciate if you redraw the circuit in another way.



The auto-transformer is widely used in the line output stage of modern TV receivers. One advantage it gives is that the leakage flux between the two windings of the double-wound transformer—that part of the flux which *fails* to link the two windings—is much reduced (though not altogether eliminated). This is valuable, because this flux makes a significant contribution to the ringing oscillation which occurs during flyback. This oscillation is admittedly put to good use in generating the second half of the scan; but leakage flux nevertheless represents an energy loss in the circuits, so should be minimised where possible.

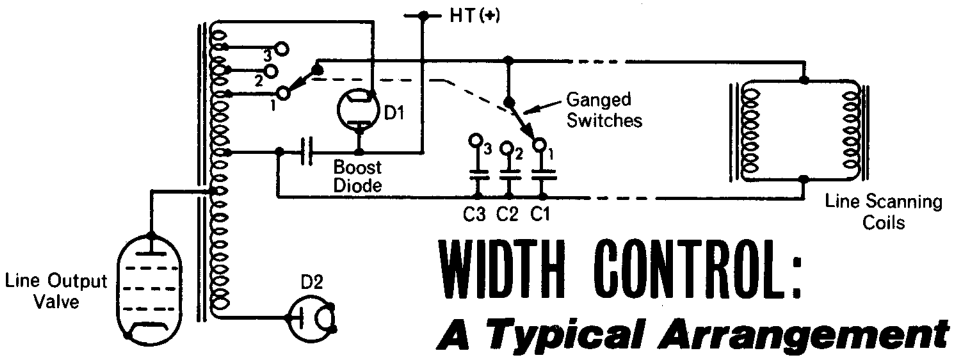
With the scanning coils now directly connected to the anode circuit of the pentode, one could reasonably expect that a d.c. current would be flowing through them; and this would cause a permanent displacement of the scanning spot on the screen. But you have just seen that, if an efficient boost diode circuit is employed, the current flowing in the transformer *reverses its polarity* at a point in time midway through the scan. This effectively makes the scanning current a.c. in nature; and since the mean value of an a.c. current is always zero, no displacement of the spot will occur.

Note that, in less efficient boost circuits, the point at which the scan ceases to be produced by the anode current of the diode and begins to be produced by the anode current of the pentode no longer occurs midway through the scan. This effectively means that the I_a of the pentode is greater than the I_a of the diode, and the average value of the waveform of current delivered to the line scan coils will no longer be zero. For this reason, it is sometimes necessary to couple the output transformer to the scanning coils through a large-value d.c. blocking capacitor, in order to block the resultant d.c. element in the scanning waveform.

Width Control of the Picture

You saw in the last Section that adjustment of the vertical size (height) of the picture can be simply made by adjusting the amplitude of the scanning waveform applied to the control grid of the field output stage. Unfortunately, control of the horizontal size (width) of the picture is not so simply achieved. The reason is that any variation in the amplitude of the waveform applied to the control grid of the line output valve would be likely to disturb both the boost and the EHT voltages (of the latter, more anon), and so to impair the linearity of the scan. Other methods of width control must therefore be found.

One such method is based on a switching, plug-and-socket, arrangement which enables the turns ratio of the line output transformer to be varied.



WIDTH CONTROL:
A Typical Arrangement

It will be seen that the scanning coils can be connected at will to a number of different taps on the transformer winding, and the viewer can switch from one to another of them until the correct width of picture is obtained. A ganging arrangement enables shunt capacitors of appropriate value to be automatically connected across the coils every time a different transformer tap is selected. This ensures that a constant total current is supplied to the selected shunt-capacitor-scanning-coil combination, whatever the width of the picture. In this way, a constant voltage is maintained across the transformer, and steady EHT and boost voltages are achieved.

(Ignore D_2 for the time being. You will see what it does on the next page.)

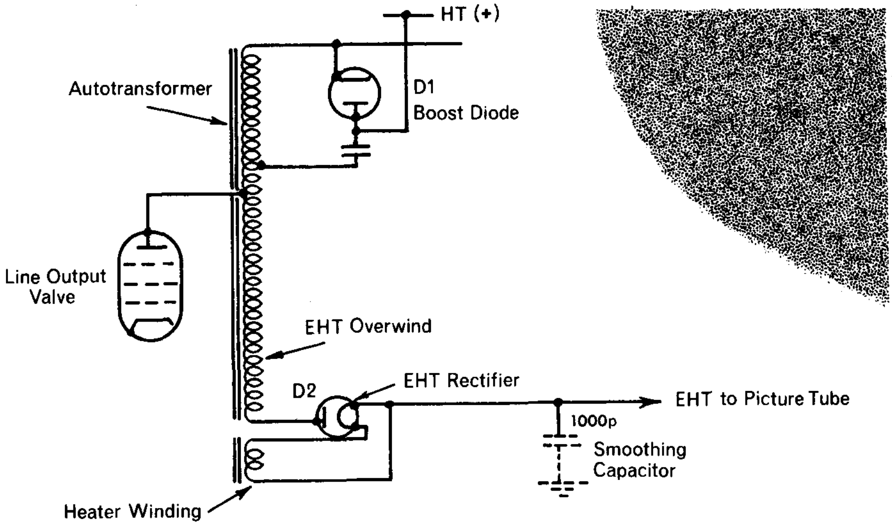
Transformer Whistling

The cause of the characteristic whistle which may be heard coming from most TV receivers is mechanical vibration of the line output transformer core at the line frequency. It is brought about by what is called the *magnetostrictive effect.* The vibration occurs at about 10 kHz when the receiver is operating on the 405-line standard—a frequency well within the audio-frequency range, though few older people will agree! On the 625-line standard, the vibration occurs at the higher frequency of about 16 kHz, and is therefore inaudible except to those with exceptional hearing.

Vibration of the transformer core can be reduced by mounting the transformer on sound-absorbing material and enclosing it in a metal container lined with foam rubber. This container also serves as a screen against r.f. radiation from the transformer which could cause interference at harmonics of the line frequency, and so in the lower operating bands of some radio receivers. Particularly vulnerable in this respect are small receivers tuned to the medium waveband and having a built-in aerial.

EHT Voltage Generation

The very large back-e.m.f. (typically of more than 2 kV) which is created at the anode of the line output valve every time it is cut off during the flyback period can be exploited by adding some extra turns to the secondary of the output transformer. The magnitude of the back-e.m.f. is in this way deliberately stepped up even higher, to a value which, after rectification, can be used to supply the picture tube with its required EHT of 15 to 20 kV. (You will see in the next Section why so large a voltage is required to operate the tube.)



How EHT is Generated from the Line Output Transformer

In the illustration above, the extra turns (they are usually called the **EHT overwind**) are shown as an additional secondary winding on the auto-transformer. When the line output valve is cut off, the back-e.m.f. pulse which appears at the anode of the valve is amplified 8–10 times by reason of the presence in the auto-transformer of these extra turns on the secondary winding.

Thus amplified, the pulse appears at the anode of the EHT rectifier (D_2 in the illustration). This is a special thermionic diode capable of handling very high voltages. The pulse is rectified in the normal way (*Basic Electricity*, page 3.19) and appears at the cathode of the diode as a positive d.c. potential of 15–20 kV.

Remember that the rate at which the back-e.m.f. pulses recur is very high indeed—10·125 times a second in the 405-line system and 15·625 times a second on 625 lines. The ripple frequency of the rectified d.c. voltage coming from the rectifier diode is correspondingly high, and the voltage therefore requires little smoothing to make it usable by the picture tube. The type of smoothing capacitor commonly used (it would have a value of about 1000 pF) actually forms part of the physical construction of the picture tube itself, and you will see how it works in the next Section.

A valve such as the EHT rectifier diode requires a heater supply of its own. In the diagram, this supply is shown to be derived from a very small extra winding, of between 2 and 6 turns only, added to the auto-transformer. It develops some 6·3 V.

EHT Voltage Generation (*continued*)

An EHT supply developed in the manner described is said to be of the "flyback-derived" type. Such supplies possess very high internal impedances—which means that they are capable of delivering only small load currents. In a TV receiver, this is actually an advantage; for the picture tube itself needs only a few hundred μA of current, and the fact that the supply cannot deliver a large current means that it is unlikely to kill you if you accidentally touch it.

Never forget, however, that the EHT supply in your TV receiver is carrying so high a voltage that it can still give you a very nasty shock indeed. It must never, in any circumstances, be touched while the set is switched on. Indeed, so dangerous is its potential that you should make it a rule never to poke about in the inside of your set—even with a well-insulated screwdriver—without pulling out the wall-plug which feeds your set with HT from the mains.

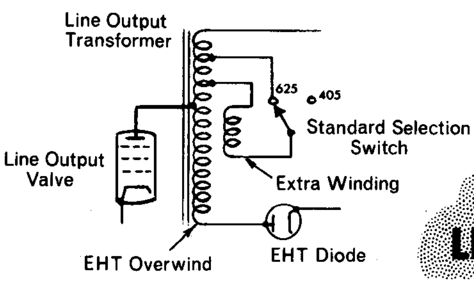
One major drawback of the large output impedance associated with an EHT circuit of this type is that the supply will have very poor regulation. This means that the EHT voltage will vary in magnitude every time the load current (which is the beam current drawn by the picture tube) changes. This happens frequently—as when a dark scene is replaced by a bright one, or when the mains supply to the receiver varies.

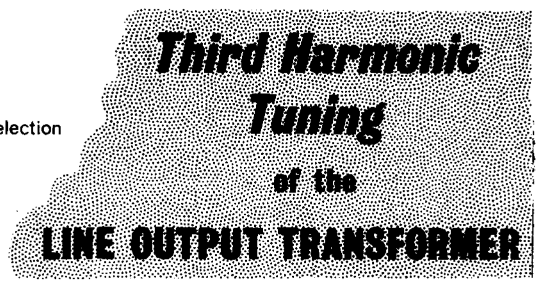
Variations in EHT voltage cause the picture size to change (picture shrinks when EHT is increased, and *vice versa*); and the extent of the changes may be sufficient to become objectionable to the viewer. The effect is less pronounced, however, in circuits in which the line output valve is used as an electronic switch, because the EHT is then dependent on the absolute magnitude of the HT voltage derived from the mains.

Third Harmonic Tuning

The magnetic coupling between the EHT overwind and the remaining sections of the line output transformer cannot be made as tight as that between the other windings themselves because of the very high voltage involved and the consequent need for extra-good insulation. In other words, the overwind cannot be wound too close to the primary for fear of a voltage breakdown between them. As a result, there is a considerable leakage inductance associated with the EHT overwind; and this, in conjunction with its stray capacitance, can give rise to severe ringing.

The most usual modern way to prevent ringing from this source is to design the output transformer in such a way that the ringing from the overwind occurs at a frequency equal to the third harmonic (actually, it is the 2·8th harmonic, but the difference is not important) of the line frequency. The phase relationship between the anode voltage of the line output valve and the ringing oscillation across the overwind then becomes such that the ringing is passing through a minimum at the time the anode voltage is reaching its *maximum*. The ringing is thus caused to be of insignificant amplitude at the critical moment of the scan.





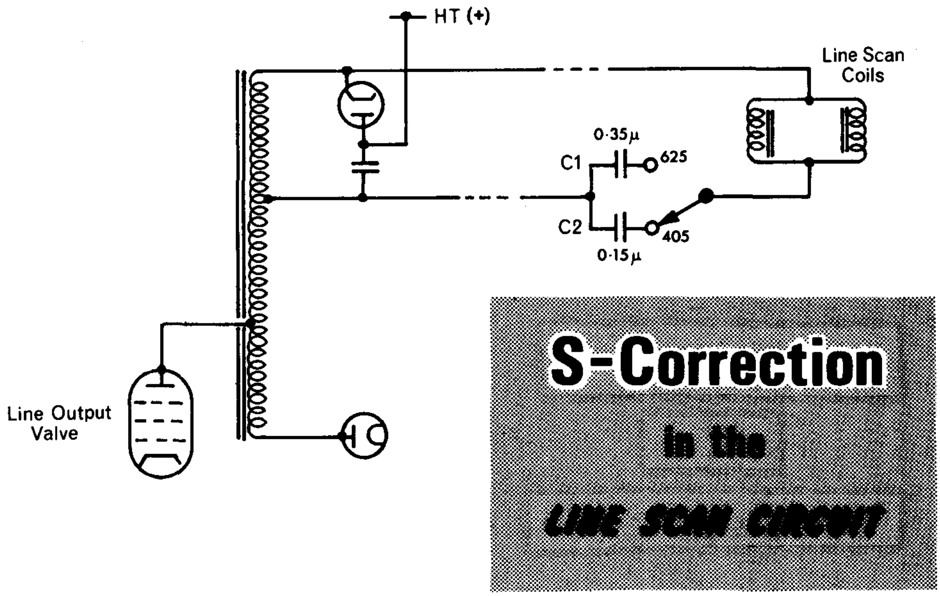
Third Harmonic Tuning (*continued*)

Because of the difference in line scan frequency between the 405- and 625-line systems, it is necessary to re-tune the transformer every time you switch standards so as to ensure that the overwind is always tuned to the third harmonic of the particular line scan frequency being employed. This can be achieved in several ways, one of which makes use of another extra winding of about ten turns on the autotransformer which is physically situated underneath the EHT overwind.

When the receiver is set for 405-line operation, this extra winding (L_3 in the illustration overleaf) is open-circuited by switch S_1, and the transformer is tuned to the third harmonic of the 405-line operation (*i.e.*, to $3 \times 10{\cdot}125 = 30{\cdot}375$ kHz). When the receiver is set for 625-line operation, the extra winding causes an increase in the coupling to the overwind, which effectively changes the magnitude of its leakage inductance. This change is arranged to be of such a value that the overwind is retuned to the third harmonic of the 625-line scan frequency (*i.e.*, to $3 \times 15{\cdot}625 = 46{\cdot}875$ kHz).

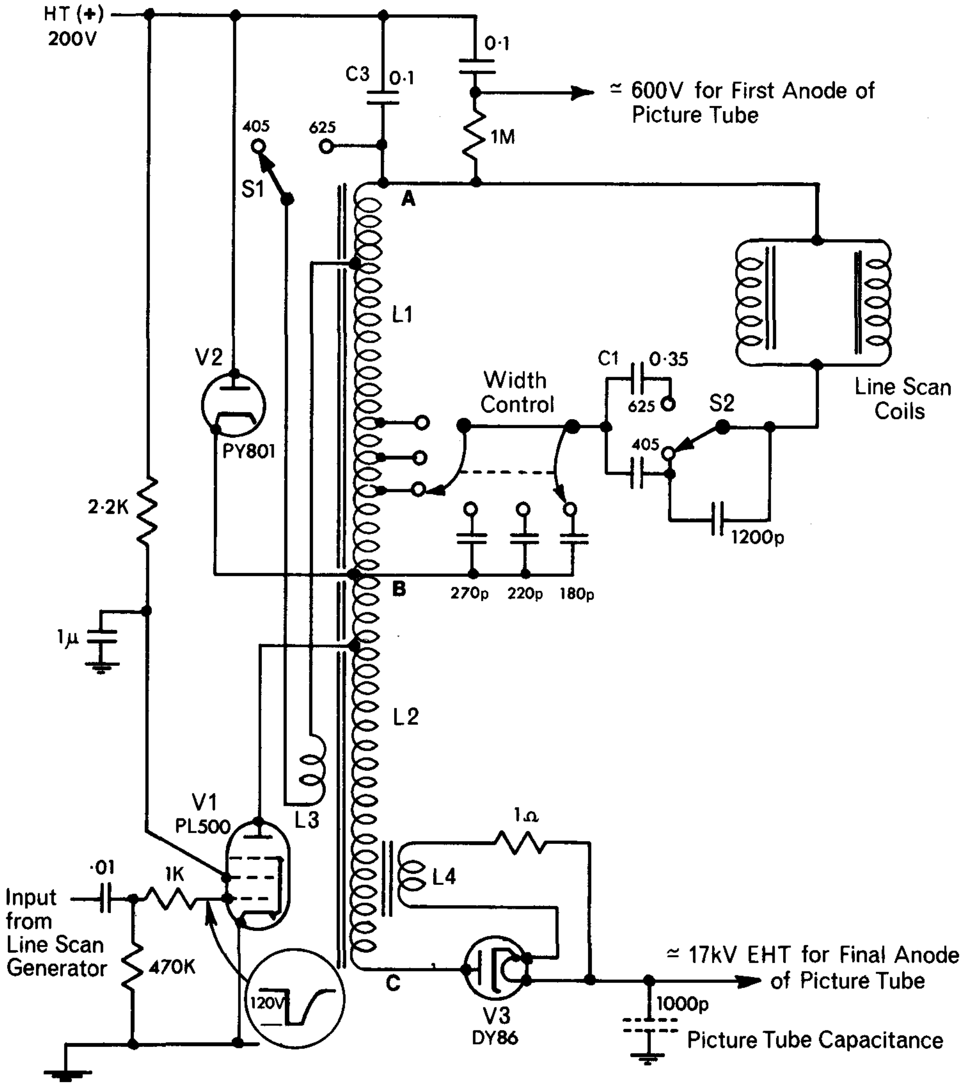
S-Correction in the Line Scan Circuit

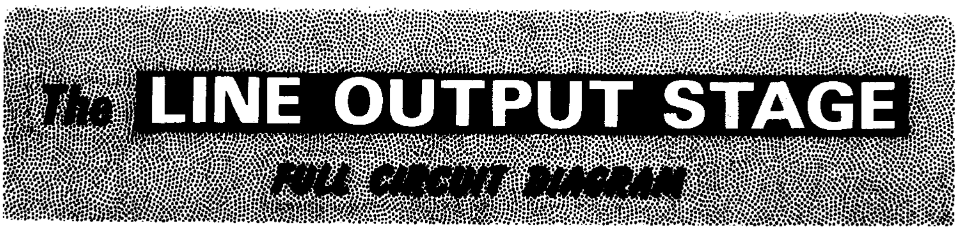
S-correction in the line scan circuit is often achieved by connecting in series with the line scan coils a capacitor whose value has been carefully selected so that it distorts the shape of the scanning current into the elongated and flattened "S" shape required. The effect of introducing into the line scan circuit of a modern flat-faced 110° picture tube a 0·1 μF capacitor is to increase the peak value of the scanning current by about 7%. This cancels out part of the inductance of the line scan coils and so introduces the desired degree of S-correction; but an explanation of exactly what happens would take you some way beyond the scope of this *Basic TV* series.



In dual-standard receivers, a different S-correction capacitor (C_1–C_2 in the illustration above) is brought into circuit every time the Standard Selection switch is operated, because of the different scan periods of the two systems.

The Line Output Stage—Full Circuit





The Line Output Stage—Full Circuit

The illustration opposite shows the full circuit diagram of a line output stage representative of modern design techniques.

The main winding (section A-B) of the output auto-transformer is labelled L_1, the EHT overwind (section B-C) L_2. L_3 is the third-harmonic tuning inductance, switched into circuit only when the receiver is set for 625-line operation; and L_4 is the heater winding for the EHT rectifier diode V_3. The 1-ohm resistor in series with this winding is used to trim the heater voltage to the correct value. To get this voltage directly would require a fractional number of turns on L_4. It is much easier to use a whole number of turns and then trim the voltage produced by adding a small resistor.

The line output valve V_1 is supplied at its control grid with a rectangular waveform having an exponential trailing edge, coming from the line scan generator. Its screen grid is connected to HT, which is of the order of +200 V.

The boost diode V_2 appears upside-down compared with the circuit you studied a few pages ago, but it works in exactly the same way and supplies charge to the 0·1-μF boost capacitor C_3 connected in series between the HT line and point A on the output transformer. The boost voltage (typically, 600 V) appearing at point A is also used to provide the potential required by the first anode of the picture tube, via the smoothing circuit formed by the 1 M resistor and 0·1-μF capacitor shown. Smoothing is necessary in this case because the boost voltage is fluctuating at the line frequency.

Width control is provided by the transformer tap selection method you already know about; and S-correction of the line scan current waveform by the alternative-capacitor arrangement labelled C_1–C_2. The switches S_1 and S_2 are, as usual, sections of the Standard Selection switch.

The Line Output Transformer—Physical Appearance

The typical line output transformer is of unusual shape. The EHT overwind, which is rather like a catherine-wheel in shape, is wound *over* the main anode winding. It is kept narrow so as to maintain good insulation, and is usually impregnated with wax to stop moisture getting into it. The heater winding for the EHT rectifier diode is wound on the opposite leg of the transformer core, and consists of wire having thick polythene insulation.

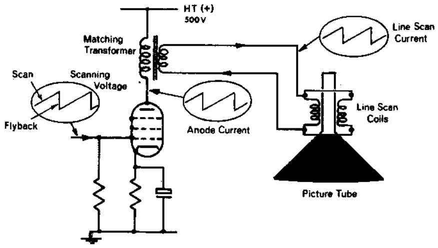
The transformer core itself is made of a ferrite material (minute particles of iron oxide fused together to form a ceramic) and consists of two U-shaped pieces clamped tightly together by securing bolts and a clamping frame. The mating faces of each U-piece are insulated from one another by thin pieces of paper, to prevent core saturation.

The EHT rectifier diode is mounted either on a tag strip on top of the transformer or in a valve holder alongside; and the solder joints associated with it (heater and anode connections) are carefully rounded off so as to make what is known as *corona discharge* from these points less likely. All sharp-pointed projections tend to concentrate the electrostatic field from the EHT voltage and so to encourage corona discharge.

If you want to see what corona discharge is like, look into the back of any well-worn, dust-encrusted TV receiver when the room is in total darkness (and preferably when humidity is high). TOUCH NOTHING—but watch out for a faint crackling noise and for small areas of bluish-white light coming from regions associated with the EHT voltage. You may even smell the ozone which is created when air is ionised by the corona discharge.

Discharges of this kind result in less EHT being available for the picture tube, and therefore in reduced picture brightness. They can also give rise to an r.f. radiation which may interfere with the receiver itself, or with others situated nearby.

REVIEW of Line Scan Development

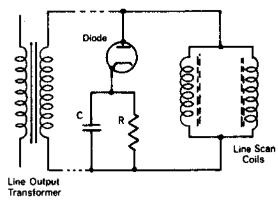


LINE SCAN OUTPUT [illegible]

The line scan output stage accepts the waveform generated by the line scan generator and uses it to produce a powerful scanning current which it supplies to the line scan coils. These coils are predominantly inductive, and have comparatively low impedance. They are coupled to the line output valve by an impedance-matching transformer.

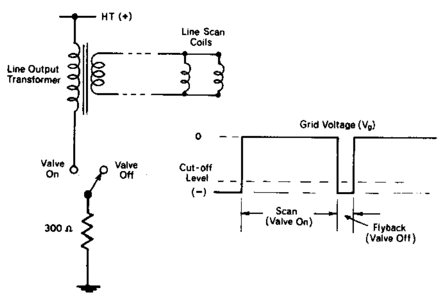
Very large back-e.m.f.'s are produced by the line scan coils during the short-duration flyback periods of the line scan. These e.m.f.'s, passing back through the impedance matching transformer, would (if allowed to do so) appear at the anode of the line output valve in the form of a ringing oscillation having a peak amplitude of more than 2000 V.

THE EFFICIENCY DIODE



They are prevented from reaching the anode by means of a diode connected in series with a capacitor which not only stores much of the energy contained in these dangerously high voltages, but puts it to good use in providing the first 40% or so of the following line scan.

In its simplest form, this diode is known as an *efficiency diode*.



The LINE OUTPUT VALVE Operated as a SWITCH

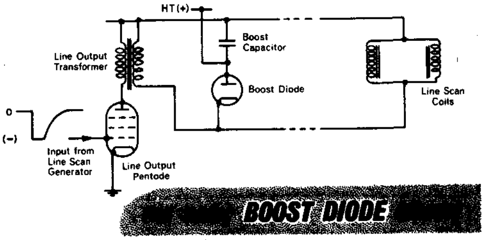
When an efficiency diode is in use, the line output valve is only required to produce the last 60% of the complete line scan. With the requirement it must fulfil reduced in this way, the valve can be operated as an electronic switch instead of as a "Class A" linear amplifier.

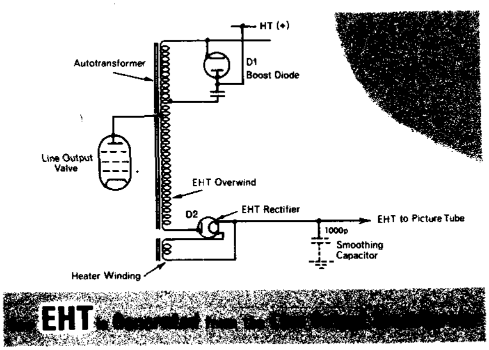
Its input waveform has a sharply rectangular leading edge, but a trailing edge with a pronounced exponential curve.

REVIEW of Line Scan Development (*continued*)

Efficiency diodes of improved design use the energy of the back-e.m.f.'s generated during line flyback to produce a positive voltage which can be applied so as to add to the value of the HT voltage delivered to the line output valve, so further improving the efficiency of the line output stage.

When the efficiency diode is operated in this way, it is known as a *boost diode*.

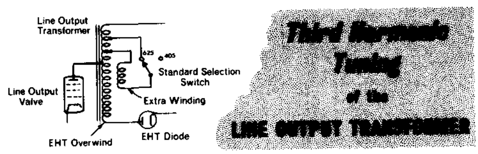




The large back-e.m.f.'s created by the line output stage are put to yet another use by means of an additional winding on the line output transformer. This *overwind* produces a very high voltage which, after rectification, is used to supply the picture tube with the EHT voltage of 15 to 20 kV which it needs for efficient operation.

The rectification is done by a small diode capable of handling very high voltages, which in turn derives its heater supply from yet another winding (of a few turns only) on the line output transformer.

Because of the high voltages involved, the magnetic coupling between the EHT overwind and the other windings of the line output transformer cannot be made tight. In consequence, there is a considerable leakage inductance associated with the overwind.



This inductance is caused to resonate with the self-capacitance of the circuit at a frequency equal to about three times that of the line scanning frequency. This ensures that the ringing produced by the inductance occurs at moments when minimum voltage is present at the anode of the line output valve.

This further way of reducing the damage which could be done by over-large back-e.m.f.'s is known as *third harmonic tuning*.

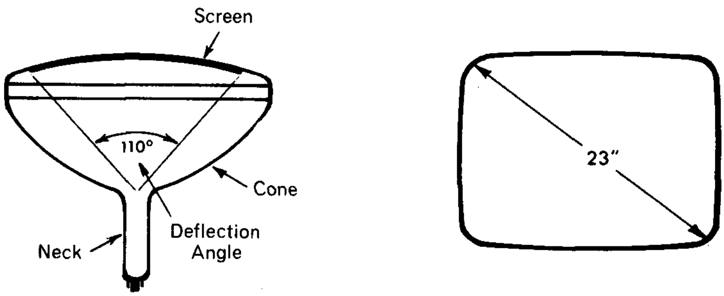
§21: THE PICTURE TUBE

You have now followed out the different routes by which the vision signal and the synchronised field and line scans are brought to the picture tube. The time has at last come to take a closer look at the component which provides the picture you see on the screen of your TV receiver, and to learn how it is activated and modulated by the different signals applied to it.

In all essentials, the picture tube in a TV receiver is little different from the types of tube used in a radar set or in an oscilloscope. All are cathode-ray tubes operating in the same basic way, and containing a similar internal-electrode structure. The essential differences between them are merely matters of size, shape and external appearance.

You know from page 1.29 that the operating principle of the TV picture tube is for the received signals to be caused to modulate the intensity of an electron beam, which has been accurately synchronised with the scanning beam in the camera tube in the studio, as it scans the fluorescent face of the picture tube. Before seeing what is involved in putting this principle into practice, you would do well to re-read the Section on the cathode ray tube in *Basic Electronics*, pages 5.100 to 5.110, for most of it applies to the TV picture tube as well.

The modern TV picture tube has a nearly rectangular-shaped screen whose dimensions approximately match the 4:3 aspect ratio of the televised picture. It is customary to denote the size of a particular receiver by quoting the corner-to-corner diagonal measurement of its screen face—17″, 19″, 23″ and so on at the time of writing, though the metric equivalents will doubtless soon be quoted instead.



The 23-INCH PICTURE TUBE

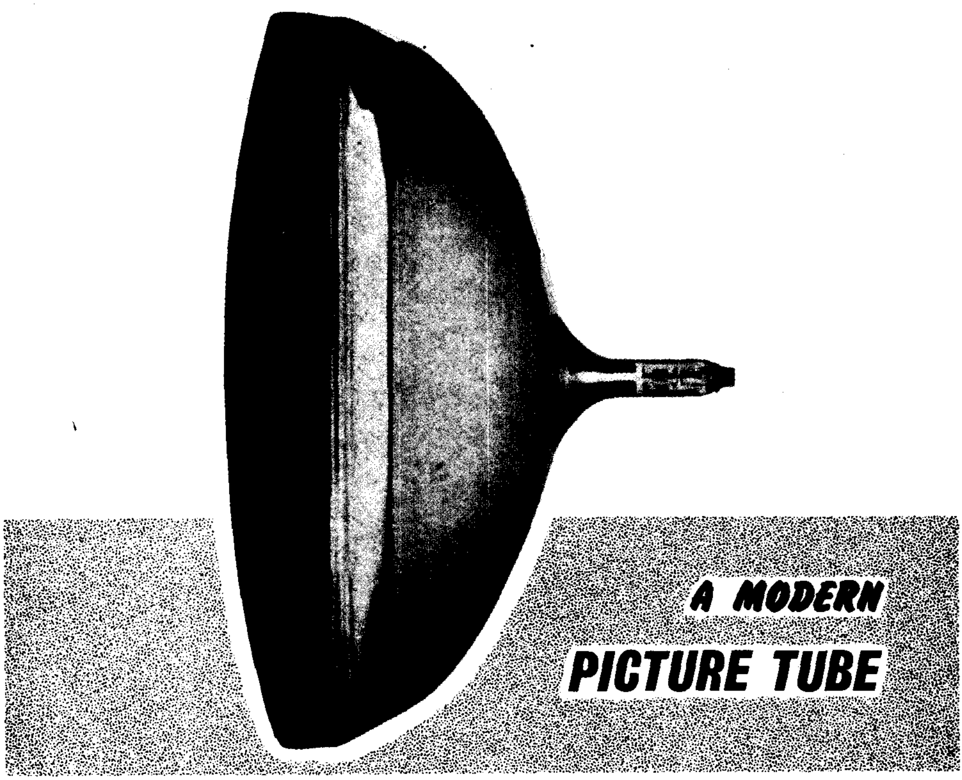
Note that the depth of the tube from the face of its screen to its plug-in base is quite short compared to the dimensions of the screen itself. The advantage of this is, of course, that the overall depth of the receiver cabinet can be kept reasonably shallow. This has not always been possible. Tubes in earlier receivers had circular, convex screens which were then covered by a rectangular plate-glass mask in the front of the cabinet. They also had long necks, which meant either that the cabinet had to be of great depth or that part of the tube neck stuck out of the back of the cabinet covered by a "top-hat" kind of extension to protect it.

The Picture Tube (*continued*)

With continuing improvements in tube manufacturing technology over the years, picture tube screens eventually became almost perfectly rectangular in shape; and the length of the neck was progressively shortened by increasing what is called the *deflection angle.* This is the angle through which the scanning beam must be deflected for it to reach the outermost (*i.e.*, extreme left-hand to extreme right-hand, and extreme topmost to extreme bottom-most) edges of the screen. The angle is measured from a point known as the *deflection centre*, which is close to where the flared-out cone of the tube joins the neck.

As a matter of historical interest, picture tubes of 1946 vintage had a deflection angle of 52° and an overall depth (from front to back) of about 18″ for a 10″ screen. As deflection angles were progressively increased through 65°, 85° and 90° (in 1953) to the present-day 110° and 114° tubes, so tube depths decreased in step until a 23″ screen in 1971 is little more than 14″ deep.

Further significant increases in scanning angle seem unlikely, for tube depth is no longer the most important limiting factor in cabinet design. The size and shape of other receiver components, and of the chassis itself, are nowadays the predominant considerations.

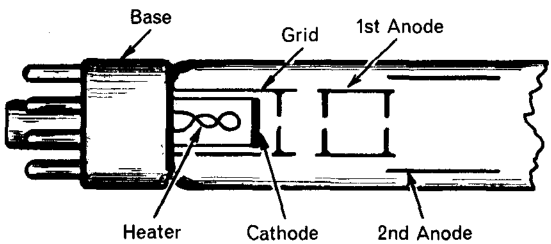


The internal electrode structure of a picture tube consists of two basic parts. The first, situated in the neck of the tube, is an **electron gun assembly**. The second part, situated on the flared edges of the cone itself, is the **final anode.** You will now see how they both work.

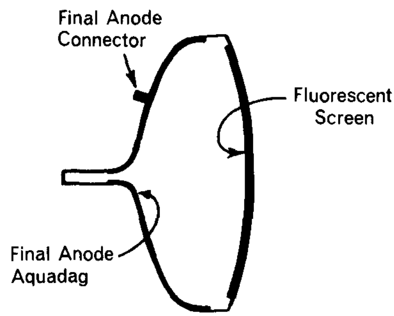
How the Picture Tube Works

The gun assembly used in a modern picture tube is similar to those described in *Basic Electronics*, pages 5.100 to 5.110. The diagram below illustrates the electrostatic method of beam focusing, though the electromagnetic method is also used.

When the *cathode* is heated, electrons are liberated from it and forced to pass through the hole in the end of the cylindrical *grid* surrounding the heater–cathode assembly by high positive potentials (typically, 200 to 800 V) on the *first* and *second anodes.* A negative charge on the grid repels the electrons as they pass through the hole in its end and concentrates them into a narrow beam. The video signal (as you learnt in Section 17) is applied to the cathode of the gun and modulates the number of electrons leaving it at any one instant of time, and so the intensity of the beam for that instant. You will recall that the polarity of the signal is such that its most negative excursions represent the highlights of the scene by supplying more electrons to the stream emitted from the cathode.



The **ELECTRON GUN Assembly**



The **FINAL ANODE**

In addition to accelerating the electron stream away from the grid by the positive voltages placed on them, the first and second anodes (as you will shortly see) prevent the beam from spreading and focus it into a tiny spot on the inside face of the screen.

After leaving the electron gun assembly, the beam comes under the influence of the *line and field scan coils* which deflect it across and up-and-down the face of the screen respectively; and it then receives its final acceleration from the *final anode.* This electrode is formed from a very thin coating of a graphite composition known as *Aquadag* applied to the inside surface of the glass cone. It carries a very high positive voltage which, for a 23″ tube, would be in the region of 18 kV. External connection to it is made by a small metal plug mounted on the outside of the tube, passing through the glass and bonded to it to maintain a hermetic seal.

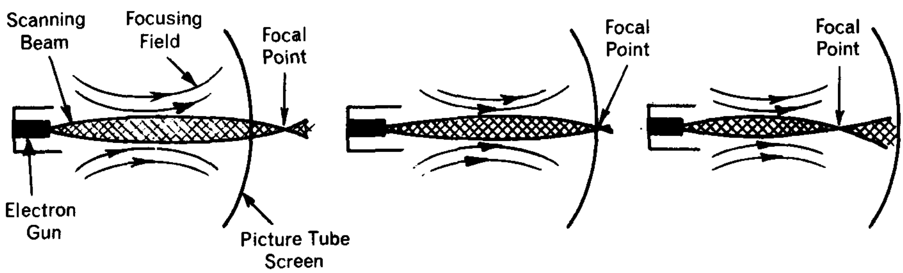
External connections to the heater, cathode, grid and first and second anodes are made through a 12-pin (*duodecal*) valve-type base bonded to the far end of the tube neck. Connection to the final anode cannot be made through this base for fear of flash-over between the closely-spaced pins, so the metal plug is used instead.

The screen of the picture tube consists of a thin layer of fluorescent material deposited on the inside surface of the glass face, the material used (generally a mixture of zinc sulphide and zinc-beryllium silicate) having a high *conversion efficiency* in that it produces a high light output when bombarded by electrons, with the right fluorescent colour for displaying a black-and-white picture. It also has an after-glow short enough to prevent smearing when fast-moving objects appear in a scene.

Focusing the Electron Beam

The stream of electrons leaving the electron gun is accelerated towards the screen by the highly attractive force of the large positive potential on the final anode. But before it can be used to trace out a raster consisting of hundreds of very fine lines on the screen, it must first be shaped into a narrow beam having a very small cross-sectional area.

This can be done by using either an electrostatic or an electromagnetic field to exert a force on the electrons as they travel towards the screen. The effect of this force is to deflect every electron in the beam slightly inwards towards the axis of the tube so that they all eventually cross the axis at a single point. By careful adjustment of the strength of the field, the cross-over point where all the electrons converge can be made to occur exactly at the surface of the screen. The result is the illumination of a tiny area of the screen (often no more than a few tenths of a millimetre in diameter) by a spot which, when the beam is made to scan, is able to trace out thin crisp lines and a clear picture. If beam focusing is poor, it will not be able to resolve fine detail, and the result will be a picture with fuzzy outlines throughout.



FIELD TOO WEAK **CORRECT FIELD** **FIELD TOO STRONG**

FOCUSING the Scanning Beam

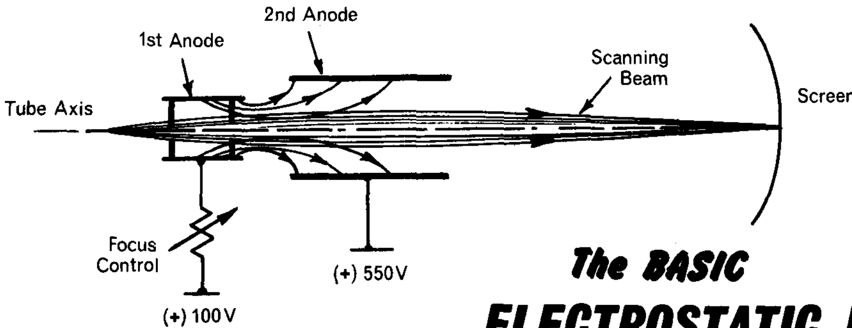
The focusing field is applied along the neck region of the tube, and is created either by an external magnet surrounding the neck of the tube (electromagnetic focusing), or by electrodes placed within the tube itself (electrostatic focusing). Both methods are used in modern TV picture tubes, and must therefore be examined. Part 5 of *Basic Electronics* provides a good introduction to them both.

Electrostatic focusing

In this method of focusing, internal electrodes are used to produce between them an electrostatic field such that an *electrostatic lens* is formed. By varying the strength of the field, the focal length of the lens can be adjusted, and with it the point at which the electrons in the stream passing through it converge. The electrodes used are the first and second anodes in the electron gun assembly—the same electrodes as are used to accelerate the electrons towards the screen.

Electrostatic focusing (*continued*)

The illustration shows a simplified form of one electrode arrangement for electrostatic focusing, but there are a good many other arrangements in common use.



The BASIC ELECTROSTATIC LENS

Remember that you are looking at a two-dimensional view only. You know that the first and second anodes are both cylindrical in shape, so that the electron beam has depth "through the paper" as well as the length and breadth shown.

The potential on the first anode is set by the focus control, and is maintained at a value permanently lower than that on the second anode. The difference in voltage between the two electrodes causes an electrostatic field to exist between them, with the lines of force running in the direction shown. When electrons in the scanning beam encounter the fields created by the two electrodes, those which are divergent from the axis of the tube (and therefore trying to cut the lines of force) are deflected by them back towards the axis. Those already moving along the direction of the axis run parallel with the field and are therefore merely accelerated, rather than deflected, by it.

By varying the potential on the first anode, it is possible to make the point of convergence of the electron beam occur at the surface of the screen. The setting of the *focus control is done by the manufacturer; it should rarely require attention during the* life of the receiver.

It may have occurred to you to wonder how focusing is affected by the differing distances which the beam has to travel when scanning the different areas of a modern flat-faced screen having a wide deflection angle. When you were studying S-correction in the two preceding Sections, you saw that this distance was greater when the beam was on the periphery of the screen than it was when it was scanning its central areas. For this reason, an electrostatic field of such strength that the electron beam it controlled focused at a point when the beam was in the centre of the screen would be too strong when the beam was scanning an outside edge, and the picture at that point would tend to become fuzzy.

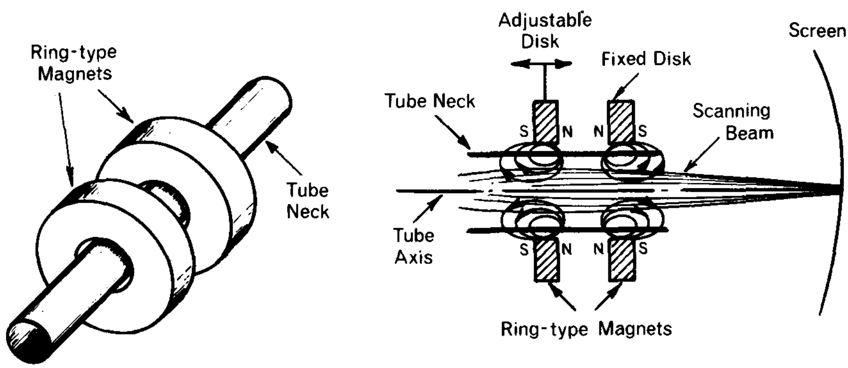
The solution adopted is, as usual, a compromise. Most manufacturers set the focus control on the first anode to a value which will cause the electrons on the beam to converge to a single point when the beam is approximately one-quarter of the way across a line scan one-quarter of the way down a field. In this way, the degree of fuzziness caused by the focal length of the beam failing to coincide exactly with the face of the screen at every point on its surface is reduced to an overall minimum. It would, in fact, not be great enough to cause much impairment of the picture even if the focal length of the beam was set at dead centre of the screen.

Electromagnetic Focusing

In this form of focusing, the electron lens is formed by an electromagnetic field rather than by an electrostatic one; but its effect on the electron scanning beam is precisely the same.

In the earlier TV receivers, the magnetic field was created by a ring-type coil assembly placed round the neck of the tube. The strength of the field, and hence the control of focus, was adjusted by varying the amount of current flowing through the coil. This method was simple to adjust; but the coil assembly tended to be bulky, and a degree of stability higher than could be maintained in practice was demanded of the voltage supplying current to the coil. When this voltage "wandered" from its intended value, focusing efficiency suffered.

In later receivers, the focusing coils were replaced by a pair of permanent magnets, also ring-shaped, slipped over the neck of the tube. Focusing adjustment was less simple than it had been before, having to be effected by mechanical movement of the whole magnet assembly; but there were compensating advantages. The essential parts of such an assembly are shown in the illustration below.



Layout of a typical ELECTROMAGNETIC FOCUSING Assembly

The two ring magnets are made of a Ferrox-type amalgam of iron and barium oxide, and one of them is adjustable lengthwise along the tube on which they are both mounted. The magnetic fields on the two rings are caused to be always in mutual opposition; and focusing adjustment is made by varying the position of one magnet with respect to its neighbour, usually with the aid of a small lever projecting from the magnet housing.

When the magnets are moved *farther apart*, the strength of the focusing "lens" is reduced, and the point at which the electrons in the scanning beam converge is moved *forward towards the screen*. When the magnets are moved closer together, the increased magnetic forces brought to bear on the lens cause it to focus the electrons to a spot at a point nearer the magnets, and so further back from the face of the screen.

Electromagnetic focusing has been widely used in TV picture tubes for some considerable time, but the space which the magnet assembly takes up along the neck of the tube, and its bulk, has led to increasing use of the electrostatic method of focusing in recent years.

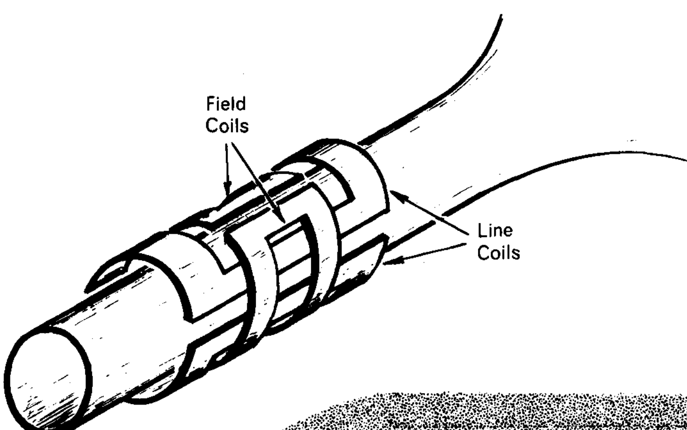
Deflecting the Scanning Beam

Now that you have seen how the scanning beam can be focused to a tiny spot at the exact point where it strikes the screen, the next thing is to see how it is deflected many times (and very rapidly indeed) across the face of the screen and at the same time (though much more slowly) down it from top to bottom.

Of the two means of deflecting the scanning beam across the face of a cathode ray tube mentioned on pages 5.104/105 of *Basic Electronics*, the electrostatic method is used extensively in CRO's and precision radar displays, but very seldom in TV receivers. The reason is that it is much easier to generate from reasonably low voltages the high scanning currents required in electromagnetic deflection than it is to generate the high voltages at low current load which are needed in electrostatic deflection. Almost all TV receivers therefore achieve deflection of the scanning beam by electromagnetic means.

Each of the two scanning coil assemblies required in the TV receiver—one for the horizontal (line) scan and the other for the vertical (field) scan—consists of a pair of coils situated 180° opposite one another around the neck of the picture tube, close to where it joins the flared section of the cone. Viewed from the front of the screen, the line coil pair for the horizontal scan (call them H_1 and H_2) is mounted above and below the neck of the tube, whereas the field coil pair for the vertical scan (V_1 and V_2) is mounted on either side of it. Remember that the horizontally-positioned coils deflect the beam *vertically*, and the vertically-positioned coils deflect the beam *horizontally*.

All the coils (H and V alike) are wound from many hundreds of turns of wire, and in their simplest form are shaped to resemble a hollowed-out saddle. This shape ensures that the coils fit snugly round the neck of the tube, and so helps to maintain a uniform magnetic field within it when the scanning currents are applied.

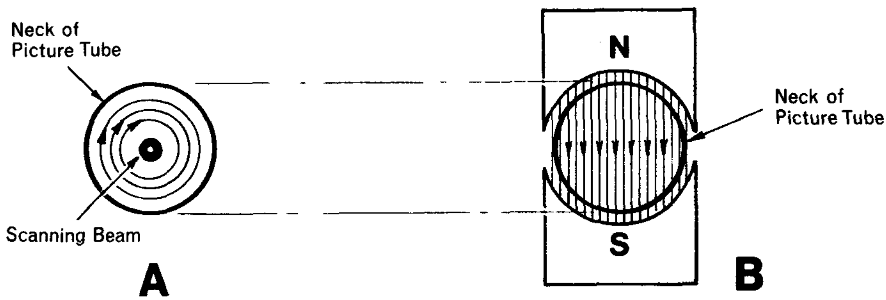


How the SCANNING COILS Fit Round the Neck of the Picture Tube

Deflecting the Scanning Beam (*continued*)

Any pencil-like beam of electrons behaves just as does a thin conductor carrying a direct current. As you learnt on page 1.45 of *Basic Electricity*, it will therefore have a magnetic field surrounding it; and the stronger the current the more intense will be the field.

Now imagine that you are able to look right through the screen of the picture tube as you sit in front of it, and that you can see the scanning beam coming towards you from the electron gun. Represent the cross-sectional area of this beam by a circle, in the centre of which is a spot which might be the tip of an arrow coming very fast indeed straight for your eye. Cast your mind back to the "Left-Hand Rule" for determining the direction of the lines of forces which are set up around a conductor when an electric current is caused to flow through it, and you will realise that the lines of force in the field surrounding the beam are as they are shown at **A** in the illustration below. In other words, they are running *clockwise* round the tip of the arrow.

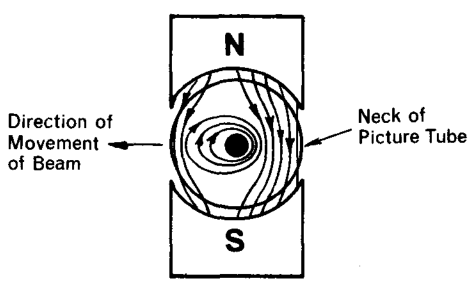


Imagine, next, that the poles of two magnets are placed one above and one below the "arrow", the top magnet being the N pole and the bottom one the S pole. The lines of force existing between these two poles will travel from N to S (*i.e.*, from top to bottom). In the absence of the "arrow", the field from the magnets would exist as a series of parallel lines of force, as shown at **B** in the illustration; and the stronger the magnets, the greater would be the strength (flux density) of the field.

Now consider what happens when the "arrow" of the scanning beam comes slicing through the beautifully straight field produced by the magnets.

Because of the relative directions of the two sets of flux lines, those on the right-hand side of the scanning beam (as you look at it) will tend to reinforce one another, since they are moving in the same direction; whereas those on the left-hand side will tend to cancel one another out, since they are moving in opposite directions. The effect will be that a *resultant* magnetic force will be applied to the beam in such a direction that the beam will be forced towards the *left-hand* side of the picture tube.

Remember, though, that all the time the distorted field of the two magnets will be straining to return to its normally undistorted condition—just as the string of a bow would seek violently to return to normal once the constraint of the archer's fingers was removed from it.



Deflecting the Scanning Beam (*continued*)

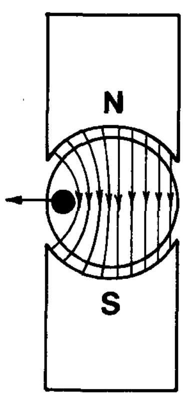
If the field produced by the two magnets is weak, there will be few lines of force to react with the scanning beam, and it will be only slightly deflected. But if the strength of the deflecting field is gradually increased from zero to a high value, the scanning beam will be completely deflected to one side, its rate of movement being governed by the rate of increase of the deflecting field.

If the poles of the two magnets were to be reversed, of course, the scanning beam would be deflected in the opposite direction. So if it is desired to deflect the beam completely from one side of the screen to the other, all that is needed is to start with the deflection field at maximum strength with the magnet poles in one position (when the beam will be completely to one side), and then gradually increase/reduce the field through zero (when the beam will be central) to maximum strength once more, but this time with the polarities of the magnetic poles reversed.

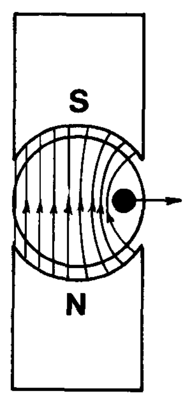
Take the line scan as an example, for it is rather the easier to understand. With zero current flowing through the scanning coils, the beam will be stationary in the centre of the screen. When a large current is passed through the line scan coils in such a direction that the upper magnet in the illustration becomes a North pole, the beam is forced over to the left-hand side of the tube—the current at this moment being said to have "maximum value in the negative direction".

Now suppose that current flow through the coils is made gradually less and less strong until it becomes zero, and is then, without any pause, made to flow more and more strongly in the opposite direction. (In electrical terms, it is said to increase linearly from maximum value in the negative direction, through zero, to maximum value in the positive direction.) The polarities of the magnet poles alter, with North becoming South and *vice versa*; and the electron beam will be forced over to the right-hand side of the picture tube.

These two states are pictured in the illustration below, the left-hand diagram showing the beam at the start of a line scan and the left-hand one showing it at the end of the scan, with current flow now maximum in the positive direction and the polarities of both magnets reversed.



Current Maximum in
Negative Direction



Current Maximum in
Positive Direction

How *Altering* the *Direction* of *Current Flow* through the Scanning Coils causes a Scan to be Traced Out across the Picture Tube

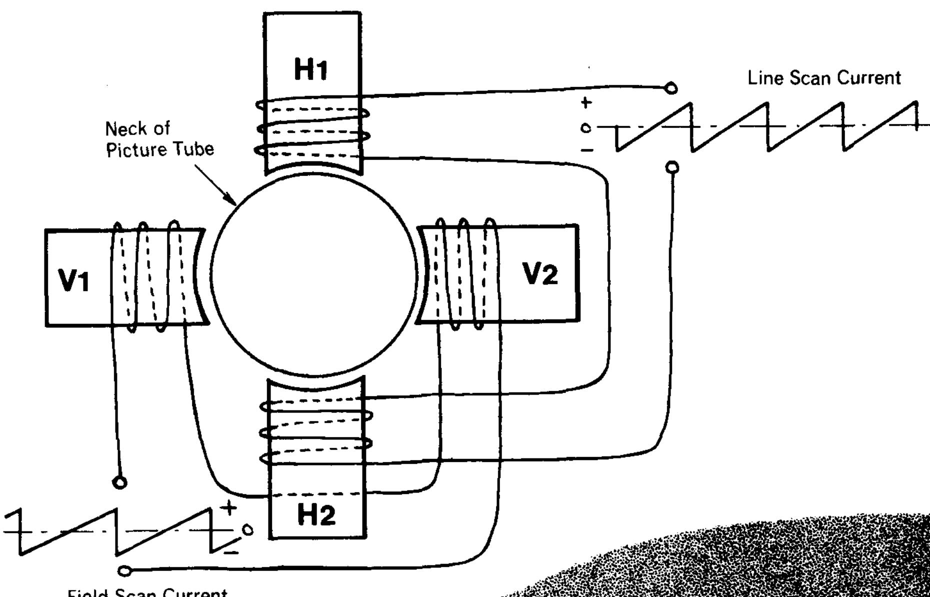
Deflecting the Scanning Beam (*continued*)

Now, with the beam hard over to the right of the tube, the direction of current flow is suddenly made to collapse from maximum in the positive direction, through zero, and (very quickly indeed) right over to maximum in the negative direction once again. This time the change in the direction of flow is not so much linear as practically instantaneous, and the beam zips back to the left-hand edge of the tube ready to begin another line scan.

Reduced to its essentials, this is what is done to produce both the line and the field scans of a TV picture tube. The two magnets are replaced by electromagnets, connected to one another either in series or (less frequently) in parallel, and currents are made to flow through them in such a way that they increase smoothly (though at very different rates) from a maximum value in the negative direction to a maximum value in the positive direction, and then collapse very rapidly indeed to their original states.

The Line and Field Scan Coils

The four electromagnets used—two of them (H_1 and H_2) for the horizontal line scan and two (V_1 and V_2) for the vertical field scan—are shown diagrammatically in the illustration below. Note that those controlling horizontal movement are positioned *above and below* the beam, and those controlling vertical movement are placed *on either side* of it. By increasing or decreasing the current in the line coils at a very high rate while at the same time much more slowly increasing the current in the field coils, a series of horizontal lines can be traced out one below the other on the screen—and a **scanning raster** is produced.



The LINE & FIELD SCAN COILS: [illegible]

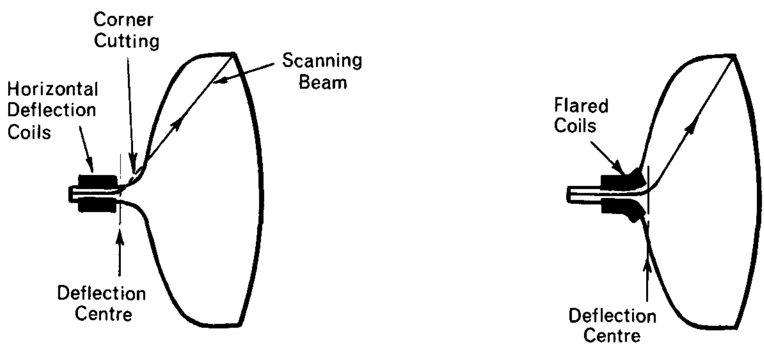
Corner Cutting

The coil assemblies used in present-day TV receivers differ greatly from the simple arrangement shown on the last page, principally because of the large screens and wide scanning angles of the modern picture tube.

You will realise, in the first place, that the larger scanning distances demanded of the line scan (remember the 4:3 width-to-depth ratio of the screen) mean that a considerably greater power output is required from the line output stage than from the field output stage. For this reason alone it is important to maintain the efficiency of the line scan at as high a level as possible.

The effect of a wide scanning angle has further importance as regards the line scan, because if the scanning coil assembly is positioned too far back along the neck of the tube, the deflected beam will be prevented from reaching the far corners of the screen by striking the neck of the tube and being absorbed by the highly positive potential on the final anode. The result would be a loss of picture at the edges of the screen.

The efficiency of the line scan circuit is improved, and *corner cutting* (as it is called) is simultaneously prevented, by so shaping the line deflection coils that for part of their length they follow the curvature of the picture tube cone. When the ends of the coils are flared in this way, they can be moved closer to the screen, and the deflection centre is moved forward with them. The problem of corner cutting no longer arises; and another advantage is that the magnetic field produced by the flared section now extends well into the cone area of the tube, so increasing its controlling influence on the scanning beam and improving the efficiency of the scan.

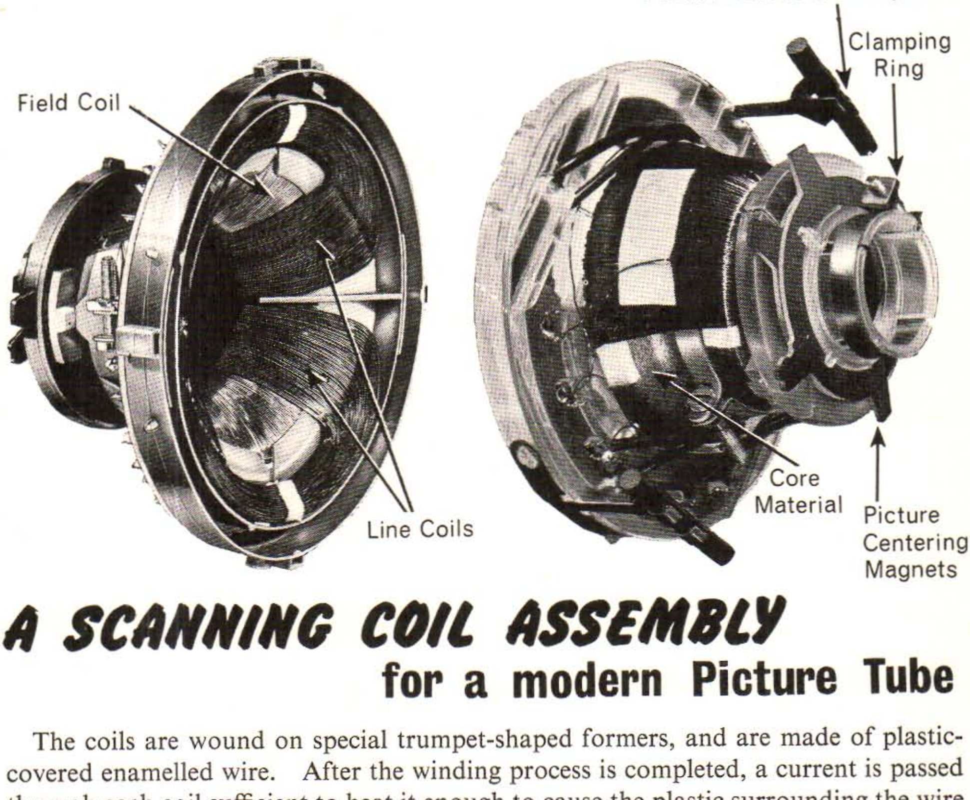


CORNER CUTTING and its *Prevention*

The problem of corner cutting is not nearly so serious with the vertical scan because of the smaller distance through which the vertical scanning beam needs to be deflected.

A Practical Scanning Coil Assembly

Pictured below are two views of a typical scanning coil assembly for a modern 110° or 114° picture tube. You will notice that the amount of flaring on the line coils is greater than that on the field coils, for reasons already explained. The two pairs of coils are clamped round a two-piece ferro-magnetic core which fits round the neck of the tube and is shaped to follow the degree of flaring in the coils.



A SCANNING COIL ASSEMBLY
for a modern Picture Tube

The coils are wound on special trumpet-shaped formers, and are made of plastic-covered enamelled wire. After the winding process is completed, a current is passed through each coil sufficient to heat it enough to cause the plastic surrounding the wire to melt and fuse together throughout the coil. Once this has happened, the current is switched off and the coil is allowed to cool. The result is a firmly bonded coil whose exterior surface shows the ridged pattern observable in the photograph.

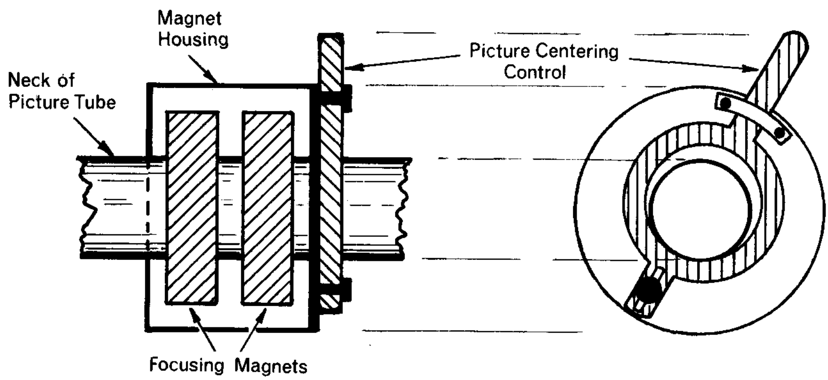
The two small *picture correction magnets* shown are positioned one on either side of the picture tube cone, each supported by two thin strips of aluminium. The magnetic fields they produce can be made to add to, or subtract from, the extremities of the field generated by the line scan coils, so compensating for the imperfections which sometimes impair the desired shape of the scanning waveform. The picture correction magnets thus assist the linearity coils (of which more anon) in straightening up the raster and improving the general efficiency of the scanning coil assembly.

The magnets are moved either by rotating them round the cone, or by bending the supporting strips. Once a good, rectangular raster has been obtained, no further adjustment of the magnets should be necessary until the coil assembly itself is changed. It is not an operation which is normally carried out by the viewer.

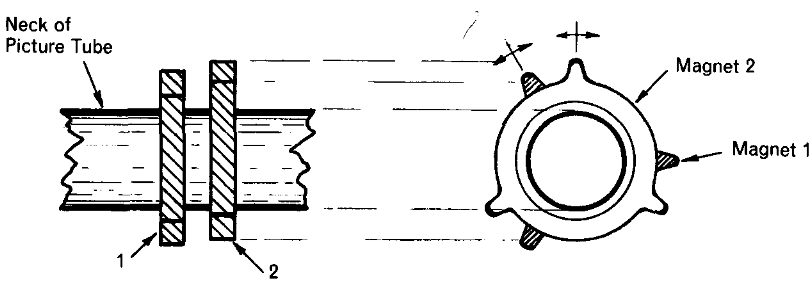
Picture Centering

Vertical and horizontal alignment of the picture on the screen is achieved, as you know, by rotating the scanning coil assembly round the neck of the picture tube. Imperfections in the scanning system, however, make it additionally necessary to provide a special control whose job it is to enable the picture to be positioned symmetrically about the centre of the screen. This *picture centering control* may take several forms, varying basically with the method of focusing the electron beam which is being used.

With the electro-magnetic method of focusing, the control usually takes the form of a thin steel disk, capable of being revolved, which is attached to the rearmost focusing magnet and is therefore magnetised by it. The field it produces, though very weak, is enough to alter the overall direction of the scanning beam sufficiently to centre the picture in the screen.



ELECTROMAGNETIC FOCUSING



ELECTROSTATIC FOCUSING

The PICTURE CENTERING CONTROL

With the electrostatic method of focusing the beam, it is usual for the picture centering control to take the form of two thin ring-type magnets. These magnets are situated immediately behind, and are supported by, the scanning coil assembly. Either magnet can be rotated independently of its neighbour.

The pattern of the magnetic field produced by the two magnets can alter the direction taken by the scanning beam, and therefore the position of the picture on the screen.

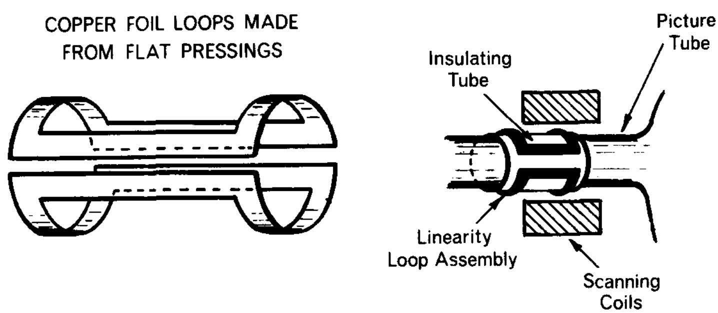
Linearity Correction

Since no scanning system is perfect and no method of S-correction faultless, some means of correcting imperfections in both the line and field scans is needed. The normal means of adjusting the linearity of the line scan is to place round the neck of the picture tube, during manufacture, a special pre-set type of control which requires little further attention during the life of the receiver.

A method of linearity control used in earlier receivers consisted of a small coil having an adjustable core, connected in series with the scanning coils. A small permanent magnet affixed to the outside of the coil gave the core a magnetic bias which caused it to approach saturation as the scanning current increased towards maximum. This caused the inductance of the coil to vary in sympathy; and appropriate adjustment of the core utilised this variation in inductance to improve the linearity of the scan.

But this method was costly, and introduced losses into the circuit. Moreover, an extra damping resistor was needed to prevent undesirable ringing during flyback; so a search was made for something better.

The latest method of controlling linearity consists of two thin metal loops made from a cheap copper pressing and stuck to a thin tube made from insulating material. This tube is slipped over the neck of the picture tube into a carefully calculated position, and fixed there before the scanning coil assembly itself is slid into position partially (but not exactly) on top of it, with one copper loop lying almost underneath each coil.



How Linearity Correction of the Line Scan is Achieved

The linearity-loop/assembly-coil combination functions as follows. Each loop gives rise to eddy currents which interact with the magnetic field produced by the coil under which it is lying. By Lenz's law, the fields of these eddy currents oppose the fields set up by the coils themselves. The electrons in the scanning beam on their way to the screen encounter, first, the field produced by the projecting loops, and then shortly afterwards the main field, opposite in direction, produced by the coils. By careful calculation of the correct axial position for the loops, the correcting field produced by them can be made to linearise the scan.

The Problem of Ion Burn

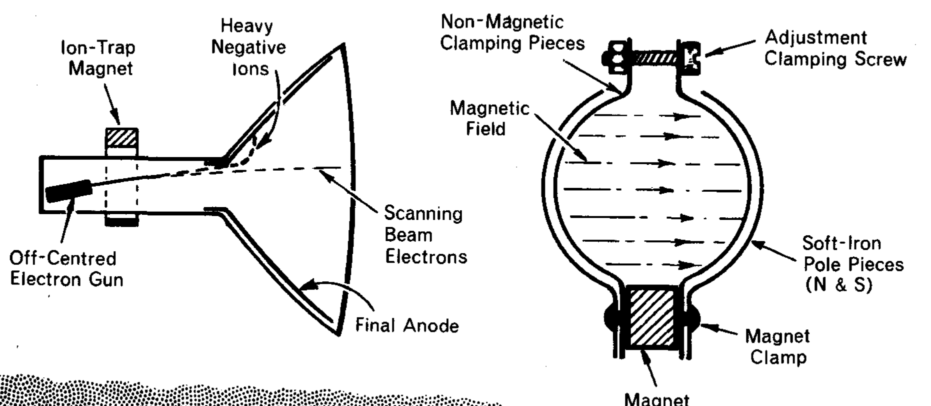
When electrons are emitted from the cathode, they are usually accompanied by a number of other negatively-charged particles called *ions*. A negative ion is an atom in which an extra electron has been captured by, and locked into, its atomic structure. Since the normal atom is neutral in charge—the positive charge of the nucleus being exactly balanced by the sum of the negative charges on its orbital electrons—the acquisition of an extra electron gives the atom an overall negative charge.

(Note, by the way, that it is also possible for an atom to acquire a net positive charge, when it is known as a *positive ion*. But since only negative ions are attracted by the positive accelerating potentials of the anode electrodes in the picture tube, only these ions are of present interest to us.)

An atom is made up of heavy protons and neutrons, and its mass is many thousand times heavier than the mass of a single electron. Negative ions are not therefore affected by the comparatively weak deflecting forces which are enough to make the electron beam scan the screen of the picture tube. They are indeed accelerated towards the screen along with the electrons in the beam itself; but then, too heavy and travelling too fast to be influenced by the line or field scanning coils, they charge straight ahead and impinge in a group at a single point in the centre of the screen directly opposite the cathode from which they came.

The result is a continual bombardment of the central area of the screen, and the rapid build-up of a burn area from 10 to 25 mm in diameter on its face. This appears as a dirty brown smear marring the centre of the picture displayed.

For many years, the problem of ion burn was tackled by a technique of mounting the electron gun assembly so that it was pointing just enough off-centre for the emitted electrons, and their accompanying ions, to be directed towards the side wall of the picture tube. A small magnet (called the *ion-trap magnet*) was placed round the neck of the tube so that its field re-directed the electrons, and the electrons alone, towards the centre of the neck of the picture tube. The heavy ions, unaffected by this small field, smashed into the side of the tube, where they were either captured by the final anode or distributed as a fine shower over the whole area of the screen.



The ION-TRAP Magnet

The Problem of Ion Burn (*continued*)

The problem of ion burn is solved nowadays by another technique whose introduction represented a significant breakthrough in picture-tube manufacturing technology.

You know that, when the electrons of the scanning beam strike the inside surface of the screen, that area of the screen which is being bombarded is made to fluoresce. What you may not have realised is that much of the light generated in this way is radiated backwards towards the cathode, and not only forwards through the screen. Indeed, because of the finite thickness of the screen material and the partial reflection from the inside surfaces of the glass face of the tube (try looking out into the darkness through a clear glass window from a well-lit room and you will appreciate the reflecting properties possessed by an ordinary sheet of glass), as much as 60% of the light is actually radiated *backwards*.

This is obviously a formidably wasteful way of operating a picture tube, and the need to improve matters led to the invention of **aluminising**.

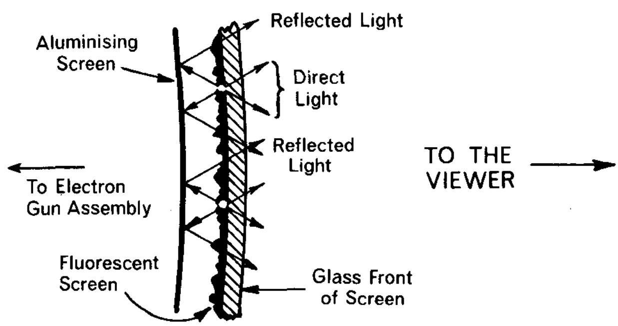
The screens of aluminised picture tubes have a very thin layer (usually only a few molecules thick) of aluminium deposited on their inside surfaces. This layer is thin enough to be almost completely permeable to the high-energy electrons in the scanning beam, but thick enough to be almost opaque to the light emitted from the screen. Since only the back of the screen is covered in this way, the aluminised layer acts as a mirror to the backward-radiated light and reflects it out of the front of the tube to add to that already being radiated in that direction. The resulting improvement in light output is astonishing.

Another advantage conferred by the aluminised screen is the increase in contrast it gives to the picture being displayed. With the backwards radiation from the screen greatly reduced, the internal reflection which used to be cast by the polished glass walls of the picture tube itself can no longer impair the quality of the picture presented to the viewer. These reflections tended to throw unwanted extra light from the brighter regions of the picture on to the areas intended to be darker, thereby noticeably reducing picture contrast.

Lastly, and most important in the context of ion burn, the aluminised layer offers good resistance to ionic bombardment. Although offering minimum opposition to the passage of the fast-moving (and therefore energetic) electrons, it offers a much more effective barrier to the slower-moving negative ions. The need for an off-centred electron gun and ion-trap magnet is no longer felt, and most modern picture tubes dispense with them altogether.

To make certain of adequate protection of the screen in such cases, however, the aluminising layer is usually made somewhat thicker than normal, particularly in the central areas of the screen.

The Principle of ALUMINISING



The EHT Smoothing Capacitor

On the outside of the flared portion of most modern picture tubes is an external coating of Aquadag covering about the same area of the cone as the internal coating which forms the final anode. This external coating is electrically isolated from the inside coating, but is connected to chassis (earth) by spring contacts.

The two coatings separated by the glass wall of the tube (glass is one of the most efficient dielectric materials) together form a capacitor having a capacitance of some 2,000 pF. This is the capacitor which, as you saw in the last Section, acts as a simple but efficient means of smoothing out the ripples in the EHT voltage applied to the final anode.

The cathode of the EHT rectifier diode is connected to the inner conductive film of Aquadag, which thus acts as one of the electrodes of the smoothing capacitor as well as forming the final anode itself.

The Direct-View Picture Tube

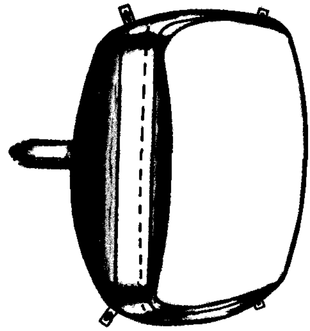
Until about 1964, TV receiver cabinets were fitted with a sheet of thick plate glass positioned in front of the face of the picture tube. Its purpose was to protect the viewer from flying fragments of glass and metal in the event (which in fact was rare) of a picture tube imploding.

An *implosion* (as opposed to an explosion) is the violent disintegration of an evacuated vessel when its outer surfaces are subjected to an atmospheric pressure greater than they can withstand. When a picture tube implodes, air rushes into the tube at the point of fracture, and the walls of the tube collapse with such force that fragments of glass and metal electrodes are sent flying in all directions.

The disadvantages of the shield were its cost (plate glass is not cheap—nor is the fitting of it), the dust which often accumulated between the plate and the front of the picture tube, so reducing the light output of the tube, the increased cabinet depth required and poor distribution of cabinet weight. From the technical point of view, an even more important disadvantage was the multiple reflections between the surface of the shield and the face of the picture tube face.

In 1964, a new concept in picture tube technology was brought to market. It consisted of wrapping a strong mild-steel band round the periphery of the tube face—the area which is subjected to the greatest tensile stresses—and bonding the two together. Normally, the band is free from stress; but if a break occurs in the tube it acts at once in opposition to the atmospheric pressures, and serves as a support to the screen and walls of the tube.

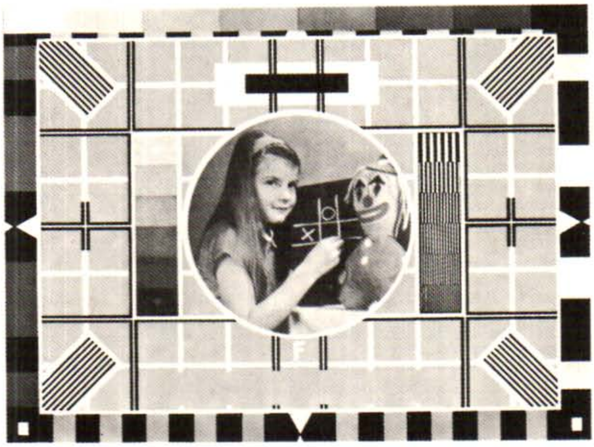
An additional advantage of the metal band is that it can be fitted with four fixed lugs, and so be used to anchor the picture tube to the cabinet. This is a much neater arrangement than were the complicated fixing methods needed earlier. A thin plastic mask slipped over the periphery of the tube face protects the corners of the faceplate when it is tightened against the cabinet and, being flexible, ensures a good fit.



The *DIRECT VIEW* Picture Tube

Test Card "F"

You must have seen the picture below on the screens of scores of TV receivers displayed in retailers' windows, and you will assuredly have obtained it on your own screen if you have ever switched on outside normal broadcasting hours. Do you know what it is?



TEST CARD "F"

Test Card "F" is a white card bearing the photograph of a very young lady playing noughts and crosses on a blackboard, and surrounded by an odd-looking pattern of circles, lines, rectangles, diagonals, triangles and squares. It is used by both the BBC and the Independent Television Authority, on both line standards, and for both colour and black-and-white receivers. The card itself is in a miscellany of colours (though you see it above as it appears on a black-and-white-only receiver screen). It is placed before one of the studio cameras and transmitted outside normal programme hours to help the service engineers, or the viewer, to adjust the various controls on the receiver so that they are set to give a stable, well-defined and properly proportioned picture.

(The age of the young lady chosen as the model, by the way, was governed by the possibility that changing fashions in make-up used by a more grown-up rival could confuse a viewer trying to assess the colour quality of the picture he was receiving!)

The dimensions of the card provide the correct aspect ratio of 4:3; and its edges carry a series of "castellations" which, in monochrome, shade off from black through various shades of grey to white. Look at the top of the test card and observe how the first few lines of it are made to consist of half-tone gradations varying from peak white in the top left-hand corner to black in the top right-hand corner. These gradations appear as separate colours on a colour receiver and are intended for use with such a receiver only, to help in colour assessment.

Test Card "F" (*continued*)

When the test card is being used, the viewer should adjust the Width, Height and Picture Centering controls on his set until the card is centrally positioned on the screen, with the centre points of its sides just reaching the edges. Note that because of the slight curvature of the screen and its mask, parts of the card may extend beyond the screen and therefore be out of sight.

The Vertical (Field) and Horizontal (Line) Linearity controls are next adjusted until the circle in the centre of the card is correctly shaped—though the horizontal control, an internal one, will normally be adjusted by a service engineer only. Moreover, since some of the controls (of which Height and Vertical Linearity are examples) are so inter-related that adjustment of one will often demand adjustment of the other, the correction of picture linearity can be a skilled operation.

Focus should be set for overall sharpness of picture detail rather than for perfect focus at any given point. This is particularly important in picture tubes using the electro-magnetic focusing technique, for this method is rather less effective over large areas than is the electrostatic method. Uniformity of focus is best achieved by observing the diagonal areas of black and white stripes in each corner, and the picture in the centre of the card.

Contrast and Brightness are set by watching the column of six half-tones situated to the left of the centre circle. The overall contrast range of the column is about 30:1, and a properly adjusted receiver should make every half-tone visible with a constant difference in brightness between each. The small lighter-shaded spots in the top and bottom half-tones in the column must be clearly visible, with no tendency to merge into surrounding areas.

The presence of reflections of the received signal caused by hills, large buildings, etc. near the receiver is often revealed by "ghost" images on the test card. These generally take the form of displaced images of the black and white vertical lines, particularly where they are close together. The noughts and crosses on the blackboard are especially good "ghost detectors".

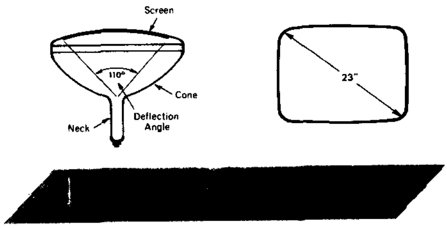
Line synchronisation is checked by observing the castellations running down the right-hand side of the test card. Faulty synchronisation shows up as a horizontal displacement of those parts of the picture which lie on the same level as the *white* castellations, and it also makes the central circle look like a cog-wheel.

The resolution and bandwith of the receiver are adjustable with the aid of the manufacturer's instructions and suitable test equipment (signal generator, test-meter, etc.), and by observing the column of six rows of gratings which appear to the right of the central photograph. (Note, however, that this is a major operation seldom necessary during the life of the average receiver.) Every row of gratings consists of a number of vertical stripes, the spacing between them representing a particular fundamental frequency. The stripes are equivalent to square-wave signals whose amplitudes vary from black to peak white, and the fundamental frequencies (in MHz) which they represent are as follows, reading from top to bottom:

On 625-line: 1·5; 2·5; 3·5; 4·0; 4·5; 5·25.
On 405-line: 1·0; 1·6; 2·25; 2·6; 2·9; 3·4.

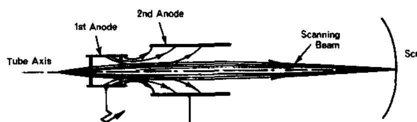
Lastly, the low-frequency response of the receiver can be checked by reference to the black rectangle lying within the white rectangle at top centre of the card. Poor low-frequency response shows up as streaking at the right-hand edges of both these rectangles—as well as on the castellations running round the borders of the card.

REVIEW of the Picture Tube



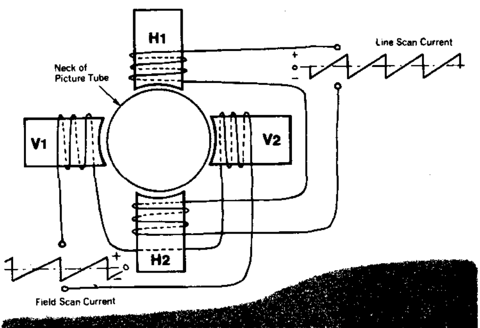
The modern TV picture tube has a nearly rectangular screen. Its size is specified by quoting the length of its corner-to-corner diagonal. Typical present-day sizes are 17", 19" and 23".

The deflection angle (nowadays normally 110°) is measured from a point known as the deflection centre, located close to the beginning of the flared section of the tube. A wide deflection angle makes it possible for the neck section of the tube to be kept short, so reducing the overall front-to-back length of the tube.



The BASIC ELECTROSTATIC LENS

Focusing of the scanning spot on the screen is usually achieved by electrostatic means. The difference between the potentials on the first and second anodes of the electron gun assembly is made variable, the object being to form the shape of the field which exists between them into an electrostatic lens.



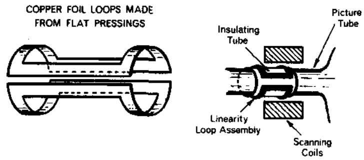
LINE & FIELD SCAN COILS:

The four coils which together make up the line and field scanning coil assembly are located around the neck of the picture tube, close to the beginning of the flared section and extending round the first part of it. The coils are connected in pairs, and are so arranged that the line (horizontal) pair is situated above and below the scanning beam, whereas the field (vertical) pair is situated on either side of it.

Every coil, together with its core material, forms an electromagnet; and both pairs of coils are electrically connected in such a way that at any point in time during the scanning period one coil of a pair is operating as a North pole and the other coil of the pair is operating as a South pole.

As the value of the current flowing through a coil pair varies from maximum in the positive direction, through zero, to maximum in the negative direction, so the polarity of any given coil changes from North to South, or *vice versa*; and the electron beam is diverted up and down the screen, or across it, accordingly.

REVIEW of the Picture Tube (*continued*)

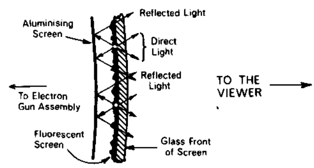


How Linearity Correction of the Line Scan is Achieved

Linearity control of the line scan is exercised by means of two closed-loop coils, fabricated from a thin copper-foil pressing and so positioned beneath the scanning coil assembly that eddy currents are induced in them by fields produced by the line scan coils.

These eddy currents give rise to magnetic fields which oppose those of the line coils themselves; and by careful positioning of the copper loops with respect to the coils, the degree of opposition can be made to compensate for any non-linearity which may be present in the raster produced by the coils.

The Principle of ALUMINISING



The technique of aluminising the inside surface of the picture-tube screen makes possible a large increase in the total light output from the front of the screen. Distortion of the picture caused by multiple internal reflections is reduced, and a much greater contrast range is achieved.

Aluminising also protects the screen from ion burn, and obviates the need for an off-set electron gun and ion-trap magnet.

§22: VISION INTERFERENCE

Most viewers will be familiar with the effects of electrical interference on a TV receiver. Unsuppressed car ignition is a major cause of trouble, the pulses of interference recurring at regular intervals determined by the speed of the engine. Its effect is to cause bands of white or black spots to move up and down the picture, and to cause exhaust-type noises to accompany the normal sound from the loudspeaker.

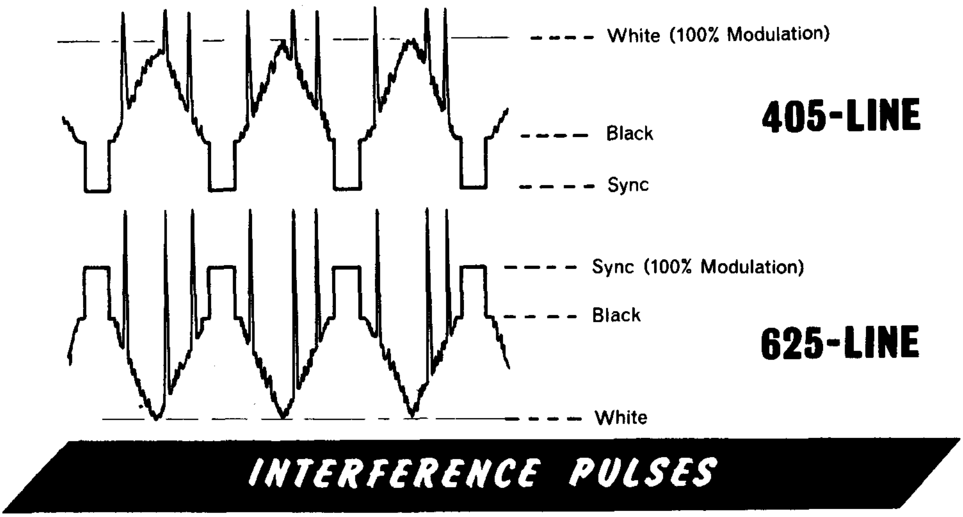
Another form of interference is caused by arcing at the brushes of some types of electric motor, *e.g.*, in some drills and electric shavers. This type of interference is continuous, and causes black or white spots to appear over the entire picture. It is usually accompanied by an intense hissing noise from the speaker. Interference of the same general kind can be caused by arcing at the contacts of thermostats in electric irons, etc., although this type of interference is usually periodic.

Car ignition interference is transmitted to the receiver directly as an r.f. wave from the spark plug or distributor leads, and should be suppressed at these points by a suppressor generally consisting of a single resistor (of, typically, 10 k value) connected in series with the coil or distributor lead. Interference from electric drills, etc. may be radiated either directly from the point of arcing or indirectly by way of the mains supply which feeds both the TV receiver and the offending apparatus. Such interference also can be easily suppressed at source.

Unfortunately, it is frequently not so suppressed; and most TV receivers incorporate some means of reducing the worst effects of sound and vision interference. The circuits which do this are known as **sound** and **vision interference limiters.** You learnt about sound interference limiters in Section 14. Now for their vision counterparts.

The Vision Interference Limiter

The first thing is to understand how vision interference manifests itself in the voltage waveforms which control the operation of the dual-standard receiver. The illustration below shows a few lines of a 405- and a 625-line vision signal immediately after detection.



Both waveforms are distorted by strong interference pulses, but note the important differences.

The Vision Interference Limiter (*continued*)

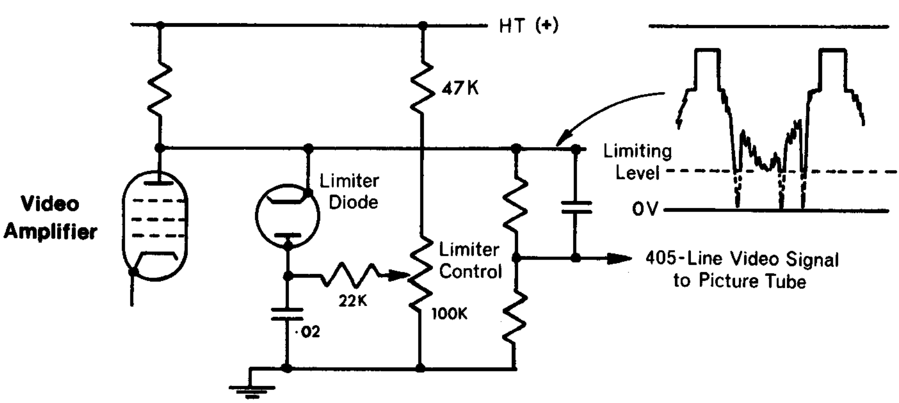
In the 405-line signal, the interference pulses cause an increase in the amplitude of the vision carrier. Because the 405-line system employs positive modulation of the vision carrier, this causes an increase in the picture signal content of the video waveform, driving it into and beyond the peak-white region and so causing white spots to appear on the picture tube. The effect is made worse by the fact that these pulses overdrive the picture tube and cause partial loss of focus. This causes the white spots to enlarge into unfocused blurs, so exaggerating the initial distortion and making it even more objectionable. Note, however, that the sync pulse content of the video waveform is not affected by the interference—a most important point.

In the 625-line waveform, the interference pulses again tend to increase the amplitude of the vision carrier; but since this system employs negative modulation, they serve to *reduce* the amplitude of the picture signal content of the video waveform, and extend into and beyond both the black level and the sync pulse level. The interference pulses therefore cause small black spots to appear on the picture tube, which are much less objectionable than the large white spots produced in the 405-line system; but the intrusion of the interference spikes into the sync pulse region is serious. In bad cases, it can impair the synchronisation of the receiver and strain the ability of the flywheel sync circuit to keep this essential function going.

Vision Interference Limiters—405-line System

A form of vision interference limiter much used in 405-line receivers consists of a diode connected either across the output circuit of the video amplifier or, sometimes, across the cathode circuit of the picture tube.

In the former case, the cathode of the diode is connected to the anode of the VA, and the anode of the diode is taken to a variable resistor forming part of a potential divider connected across the HT supply. This resistor enables the limiting action of the diode to be controlled by the viewer, whose action adjusts the positive potential applied to the anode.



An Adjustable *VISION INTERFERENCE LIMITER*

Vision Interference Limiters—405-line System (*continued*)

The anode potential of the diode on the last page is normally set a little below the level of the (negative-going) video signal representing peak white. Under normal operating conditions the diode is reverse-biased and therefore non-conducting; but when an interference pulse appears superimposed on the video signal, of sufficient amplitude to extend beyond peak white level, the cathode of the diode will become negative with respect to its anode, and the diode will conduct.

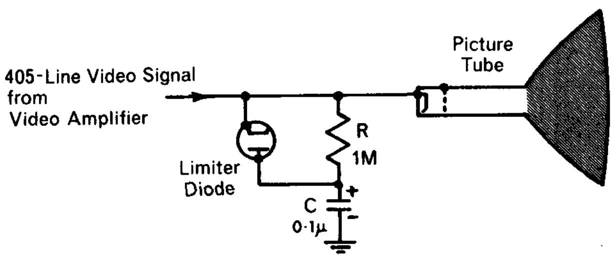
When this happens, the capacitor connected between the diode anode and chassis is placed across the video amplifier, and the negative spike of the interference pulse is absorbed as its charging current.

In this way, the amplitude of the interference pulse is *limited* to the operating level of the diode. The *limiter diode* thus makes no attempt to eliminate the interference; it merely restricts it to a pre-set level. In doing so, it prevents the picture tube from being overdriven, so preventing the white spots produced by the interference from becoming defocused (and highly objectionable) on the screen.

One obvious disadvantage of this particular circuit is that the limiting action depends on the *Contrast* setting of the receiver. If the operating level of the limiter is set close to the peak-white level of a particular video signal and the contrast is then increased, the limiting action will take place earlier, and part of the picture signal itself will be clipped. If, on the other hand, the limiter is set to operate at a higher level, a correspondingly greater level of interference must be tolerated.

The only other solution, of course, is for the viewer to reset the limiter control potentiometer every time he operates the *Contrast* control. This he does by rotating the control until the picture begins to turn milky-white, and then turning it back again until the picture just returns to normal.

Many circuits have been devised to overcome the disadvantages of the simple limiter circuit described, some of them completely self-adjusting in operation. Circuits of this type use the peak-white level of the video waveform to provide the anode potential for the limiting diode, usually with the aid of a simple RC integrating circuit. Whenever an interference pulse arrives, the diode conducts because its anode potential cannot change fast enough, and the interference pulse is short-circuited through the diode. When the *Contrast* setting is altered, the integration circuit supplying the diode anode re-adjusts automatically to the new peak-white level.



A Self-Adjusting VISION INTERFERENCE LIMITER

A disadvantage of this type of circuit (an example of which is shown, with the limiter diode this time connected across the cathode circuit of the picture tube) is that, in order to maintain charge on the capacitor C, the diode must conduct slightly on the whitest part of the video signal. The result, of course, is that the quality of the highlights of the picture will be somewhat impaired.

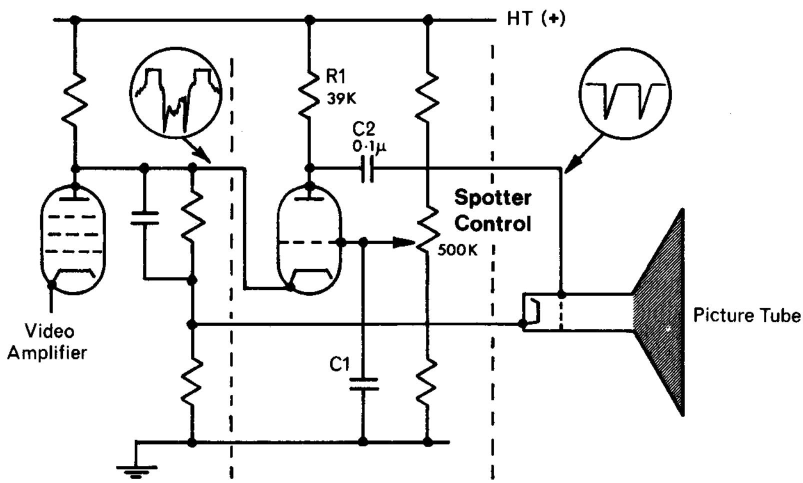
405-line Vision Interference Limiting—The Black Spotter

The best it is possible to do with the 405-line vision interference limiter is to restrict the interference pulses to a level not much greater than peak white; but this does not prevent the white spots from appearing on the screen. This is where the *black spotter* comes in.

A black spotter is a circuit which accepts those interference pulses which exceed peak white, amplifies them, and then applies them to the picture tube *in opposite phase* to that of the video signal itself. In this way the white spots are converted into black spots, without affecting picture focus; and the interference becomes much less noticeable. In some circuits, the amplification of the spotter (and therefore the amplitude of the anti-phase interference pulses) is made adjustable so that the black spots can be made to show up as grey—thus becoming even less noticeable.

There are two basic methods of black spotting. In the first, the interference pulses which exceed peak white are amplified, inverted and applied (now positive-going) to the cathode of the picture tube along with the normal negative-going (and noise-carrying) video signal. This causes the picture to black-out every time an interference pulse occurs.

In the second method, the interference pulses are amplified but not inverted, and are then applied (still negative-going) to the grid of the picture tube—the video signal being applied to the cathode of the tube as usual. As you know, putting a negative potential on the grid has precisely the same effect as putting a similar positive potential on the cathode; so the result of this type of connection is the same as that of the first. A black spotter circuit based on this second method is shown in the illustration below.

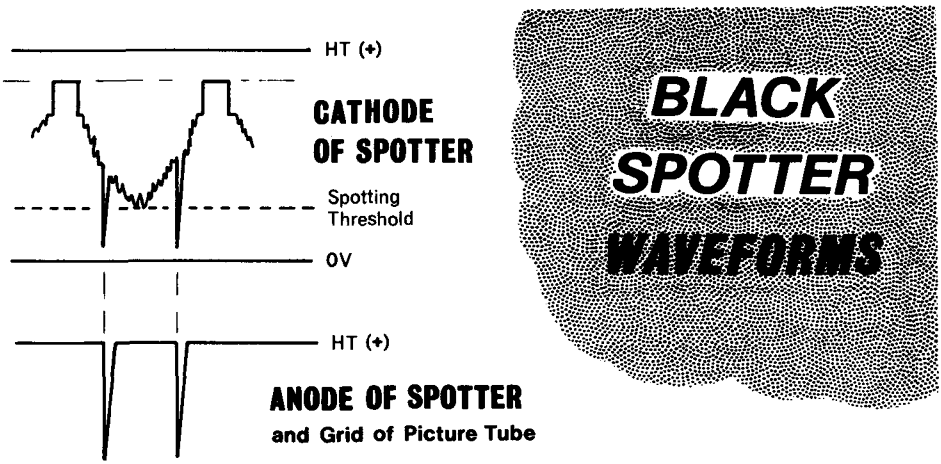


The **BLACK SPOTTER**

The Black Spotter *(continued)*

The spotter itself in the circuit shown on the last page is a triode valve functioning as a grounded-grid amplifier. Its input signal is applied to its cathode directly from the anode of the video amplifier, and its grid is earthed, insofar as a.c. is concerned, by the capacitor C_1.

The triode is normally reverse-biased, by a positive potential set on its grid by the spotter control, to a voltage *slightly lower* than the voltage which represents peak white at its cathode. Thus the valve can only conduct at times when the signal extends beyond peak white. At all other times its presence has no effect at all on the picture signal. Whenever an interference pulse causes the video signal to exceed peak white, however, the cathode of the spotter becomes negative with respect to its grid, and the valve passes anode current for the duration of the pulse. This causes an amplified version of the pulse to appear across the anode load (R_1), which is applied to the grid of the picture tube through the coupling capacitor C_2.



It is theoretically possible, by careful adjustment of the spotter control for a given contrast setting, to make the amplitudes of the interference pulses fed to grid and cathode of the black spotter exactly balance each other—thereby achieving perfect cancellation. In practice, however, adjustments of this sort can seldom be maintained for long because the unpredictable and varying nature of the interference calls for constant contrast adjustment. Black spots are therefore usually accepted as the lesser of two evils.

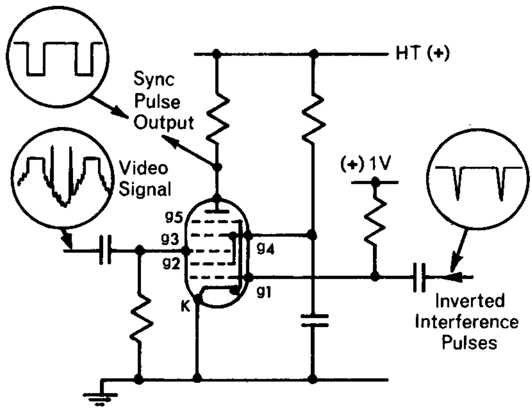
The 625-line Vision Interference Limiter

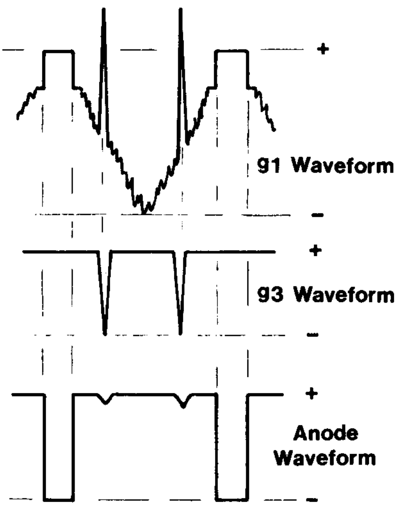
Interference pulses on the 625-line video signal cause, as you know, only black spots to appear on the picture tube and are therefore much less objectionable than are similar pulses on the 405-line signal. There is obviously no need for black-spotting, and all that need be done as far as picture quality is concerned is to limit the interference pulses to the level of the sync pulse tips, so as to avoid overloading the video amplifier. This can be done by simple limiter diode circuits like that used for the 405-line signal.

The 625-line Vision Interference Limiter (*continued*)

What is really important, however, is the effect that 625-line interference pulses could have on the synchronisation of the receiver. These pulses, as you know, extend into the sync pulse region of the video signal and so could cause faulty triggering of the scanning generator circuits. This would be particularly serious if the interference was sustained, because the flywheel sync circuit would then be unable to maintain control.

A circuit which does much to overcome the problem uses the interference pulses themselves to control the conduction time of the sync pulse separator valve. When controlled in this way, the separator is said to be *noise-gated.*





The NOISE-GATED Sync Pulse Separator

The valve used in the circuit is called a *pentagrid,* or *heptode.* It has seven electrodes —a cathode, an anode and five grids. Grids 1 and 3 are control grids, isolated from one another by two screen grids (2 and 4) which are linked together internally. Grid 5 is the suppressor grid.

Interference pulses of greater amplitude than the tips of the sync pulses are amplified and inverted with the aid of a biased amplifier such as that used for black-spotting, and are then applied to Grid 1 of the sync pulse separator. Their amplitude is sufficient to cut off anode current flow in the valve whenever they occur.

The video signal, together with its interference if present, is applied to Grid 3, and its sync pulse content is removed from the picture signal in the usual way by grid current flow. But whenever an interference pulse occurs, the valve is immediately cut off by the negative pulse reaching Grid 1, so the positive-going interference pulse on Grid 3 is effectively neutralised. (In practice, the mutual cancellation is somewhat less than perfect and a small residual interference pulse often occurs at the anode, but it is too small in amplitude to cause any trouble.)

Note that Grid 1 is taken to a small positive potential of about 1 V so that the valve is forwarded-biased in the absence of an interference pulse.

Some circuits carry a further refinement. They apply the negative gating pulse to Grid 3 through a variable resistor so that its amplitude can be adjusted for best cancellation of the interference.

§23: AUTOMATIC GAIN CONTROL

The purpose of automatic gain control (AGC) in a TV receiver is to maintain the amplitudes of the sound and video signals applied to the loudspeaker and picture tube, respectively, at a pre-determined level set by the viewer by operating the Volume and Contrast controls.

To do this, the AGC circuit must continuously monitor the amplitudes of the received sound and vision r.f. carriers, and so control the gain of all the sound and vision sections of the receiver that the gain of any section is automatically increased when the received signal is low, and automatically reduced when the received signal is high. To be perfectly effective, the response time of the AGC circuit should be short—so that, in addition to responding to *gradual* signal variations such as fading, it is also capable of reacting quickly to any *rapid* change in the strength of the received signal—as may occur when the set is switched to another channel.

Most AGC circuits control the gain of a TV receiver by varying the bias voltages applied to the grids of either or both of the r.f. or i.f. amplifying stages; and they do so in much the same way as AVC voltages are used to control the gain of a broadcast radio receiver.

You might think at first that a single AGC circuit, functioning from either the sound or the vision signal, would be all that is needed to control the common level of both sound and vision signals in a TV receiver. This would indeed be true if you could be sure that both sound and vision carriers—two completely separate signals of different frequency—were always affected during transmission in exactly the same way, and that their relative amplitudes on leaving the transmitter were always the same. In practice, of course, you could seldom be sure of either.

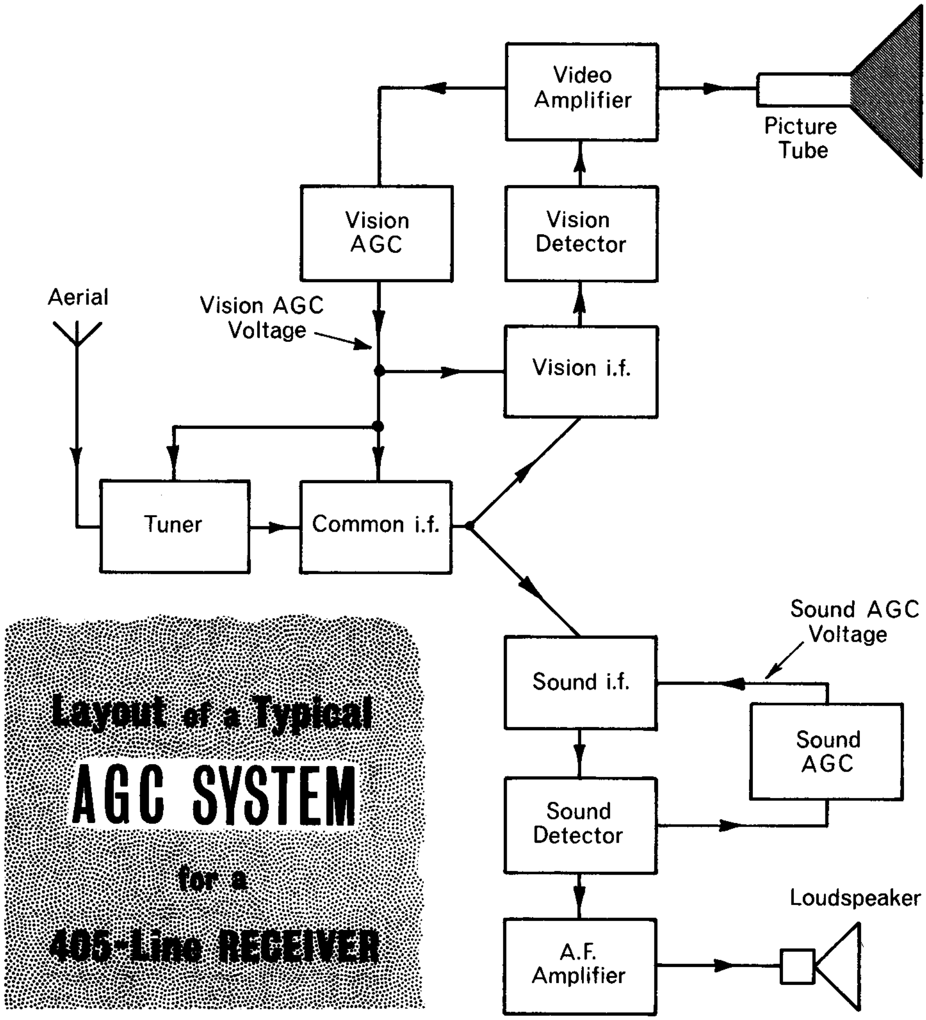
Nevertheless, some relatively low-priced receivers do indeed operate on this principle, controlling the overall gain of both the sound and vision sections of the receiver by means of an AGC voltage derived from the strength of the vision carrier. Note that the common AGC in such receivers is *never* derived the other way round—from the strength of the sound carrier. This is because the human eye is much less tolerant of distortion in a reproduced image than is the human ear of distortion in reproduced sound. (If you want proof of that statement, consider all those young people who cheerfully accept atrocious distortion on their portable transistor radios, but would object strongly to a fraction of such distortion on the displayed picture of their favourite TV programme).

When separate sound and vision AGC circuits are employed, it is usual for the vision AGC to be made to control the gain of the tuner and of any common i.f. stages, in addition to controlling the gain of the vision i.f. stage. The principal reason for this is to preserve the quality of the picture signal; but this method of operation also exerts some degree of control over the sound signal, and so gives the sound AGC circuit less work to do.

AGC circuits usually measure the amplitudes of the two r.f. carriers either at the sound and vision detector outputs (where you will remember that the output waveforms are caused to be exactly proportional to the carrier amplitudes) or (in the case of vision AGC) at a point immediately following the video amplifier. Various methods of AGC will be described later in this Section.

A Typical AGC Layout—405-line System

The block diagram below shows the layout of a typical 405-line AGC system in which separate sound and vision AGC circuits are employed. Note, nevertheless, that even here the sound AGC circuitry lies "within the control loop" of the more important vision AGC circuit.



AGC of the Sound Carrier

Only in the 405-line system, of course, is AGC for the sound carrier required; for the 625-line sound carrier is frequency-modulated, and carefully limited to a constant amplitude before detection.

In the 405-line system, where the sound carrier is amplitude-modulated, AGC is usually derived from the d.c. output of the sound detector. This voltage is then used to control the gain of the sound i.f. amplifying stages in the manner described in Section 13, when the functioning of IF Amplifier B of the British Dual-Standard Receiver was discussed.

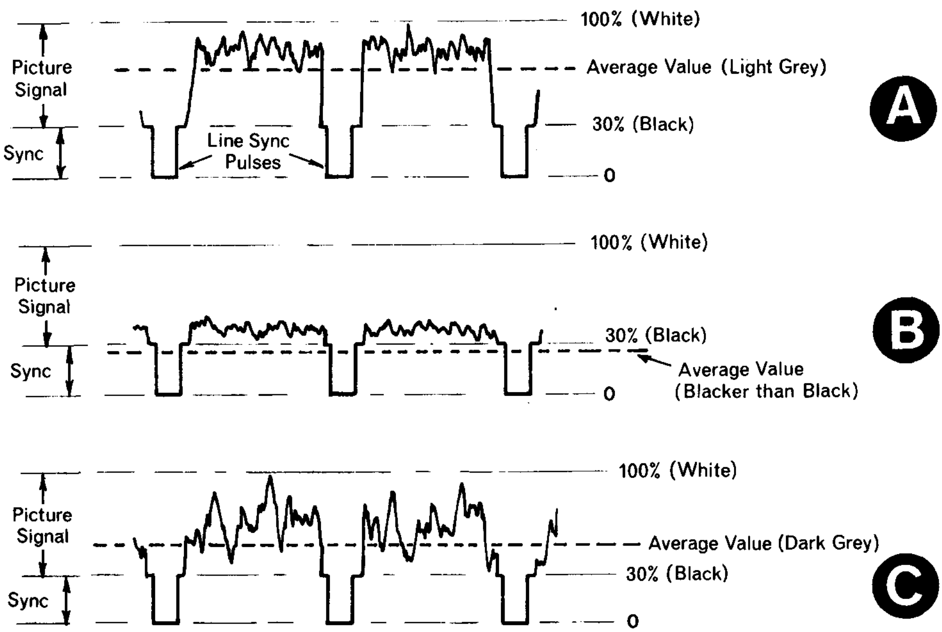
AGC of the Vision Carrier

One of the biggest problems associated with vision AGC in any system is that of obtaining an accurate indication of the amplitude of the received vision carrier. It is no good trying to measure the amplitude of the actual r.f. carrier before detection, because its average value is always zero (as is the average value of any truly a.c. waveform). Nor can a satisfactory indication be obtained by measuring the amplitude of the detected modulation (as is done in sound AGC systems), because of the peculiar nature of the modulation. As you know, video modulation of the vision carrier is either wholly negative (as in the 625-line system) or wholly positive (as in the 405-line system).

The difficulty is best realised by considering the illustration below, which shows a few lines of the video modulation of the same (405-line) carrier at three different instances in time. At **A**, the picture signal content of the modulation is predominantly white—as it would be if a sunlit snowscape were being televised. At **B**, the picture signal is predominantly black, as it would be if a night scene were being shown, or if no picture signal at all were present during a slow scene change or pause. The video waveform at **C** is typical of that representing a complex scene containing widely contrasting tones, *e.g.*, a snow scene containing dark shadows thrown by sunlit trees. Here the *average* value of the video waveform is dark grey.

In all three of the cases illustrated, the average value of the video waveform is quite different. Which of them is the correct one to use?

Nevertheless, despite this demonstration that perfect results cannot be obtained in the estimation of the amplitude of the vision carrier by measuring the average value of its video modulation, AGC circuits which rely on just this method are in fact widely used in the cheaper TV receivers—especially those designed for 405-line reception only. The reason is their extreme simplicity.

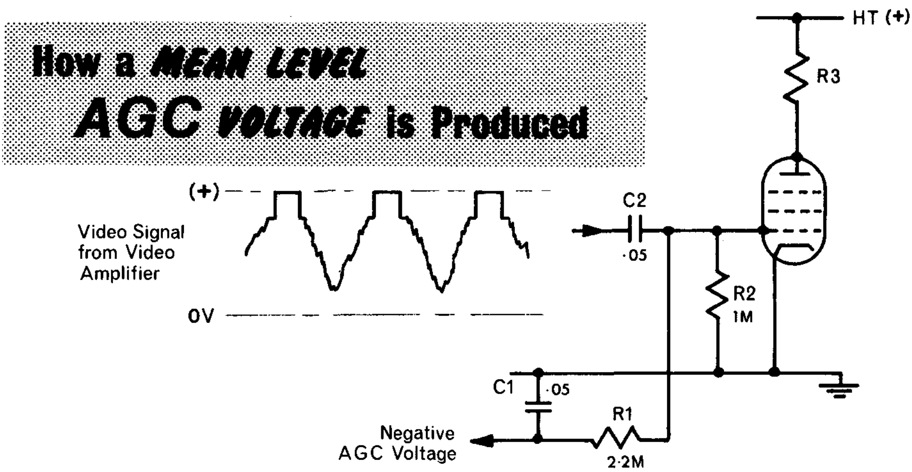


Mean-level AGC

Apart from its simplicity, the main technical argument in favour of using the average (mean) level of the de-modulated video waveform to produce an AGC voltage is the fact that abrupt changes in tonal content between scenes are comparatively rare—save sometimes when changing channels, in which case it is reckoned that the viewer will accept some adjustment of the Contrast control as an acceptable chore. Moreover, the method is equally suitable for both 405- and 625-line systems, without the need for special switching.

Much the most widely-used method of producing a mean-level AGC voltage is to make use of the negative voltage appearing at the grid of the sync separator valve. You will recall that this voltage is caused by leaky-grid action when the positive-going sync pulses of the video waveform from the anode of the video amplifier are applied to the grid. The greater the amplitude of this waveform, the greater the magnitude of the negative voltage produced. It follows that the average value of this voltage gives an indication of the mean amplitude of the video waveform, and therefore of the average magnitude of the vision carrier (bearing in mind the limitations just discussed).

Since no polarity inversion is required, all that is needed before this negative voltage can be used to control the gain of the r.f. and i.f. stages is to find some means of smoothing the variations in its amplitude. This is done with the aid of a simple integration circuit (low-pass filter) such as that formed by C_1–R_1 in the illustration below.



The time constant of the integration circuit, $C_1 \times R_1$ seconds, needs to be at least as long as five line periods lest the AGC voltage developed across C_1 should progressively leak away between the intervals of being "topped-up" by the next succeeding sync pulse. In practice, a much longer time constant is required because, during the period of the field sync pulse, the picture signal content of the video signal is suppressed for at least 15 lines (20 lines in the 625-line system)—during which time the AGC voltage, if left to itself, would fluctuate considerably between each field pulse period, with unsteadying effect on the gain of the receiver.

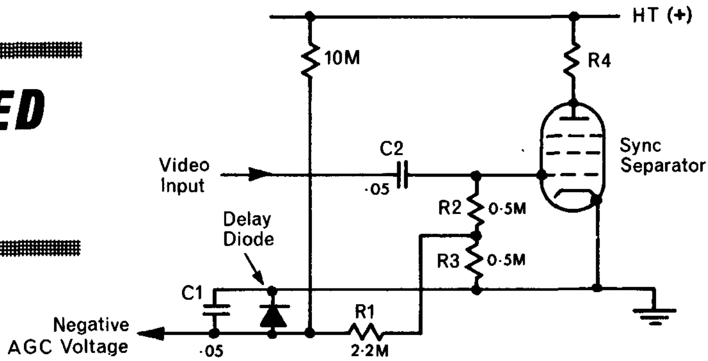
For this reason, the time constant of the integration circuit is generally made equal to about five *field* periods, typical values being 100–200 ms. Taking the components C_1, R_1 shown in the illustration, their time constant is $0{\cdot}05\,\mu F \times 2{\cdot}2\,M = 0{\cdot}11$ seconds, or 110 ms. (Remember that microfarads × megohms give a time constant measured in seconds.)

Delayed AGC

All AGC circuits suffer from the disadvantage that a negative control voltage is produced from *all* signals received, not only from the strong ones. The trouble about this is that as much gain as possible is needed to boost weak signals reaching the r.f. and i.f. stages, and anything which controls or limits this gain is undesirable. Since much less gain is required for the stronger signals, some form of lag or delay is clearly required to prevent the AGC circuit from operating until the received signal has exceeded a certain threshold. Once this level has been exceeded, the circuit can come into play to control receiver gain in the normal way.

A popular way of introducing a delay into an AGC circuit is to connect a diode across the AGC line with its anode connected through a load resistor to a positive potential, such as HT(+). When weak signals are being received, the negative voltage built up on the AGC line is quite small; and the reverse bias which this voltage applies to the diode anode is much less than is the forward bias offered by the HT line through the anode load. The diode therefore conducts through its anode load and places a near-short-circuit across the AGC line, holding its potential at a little above zero. The lack of a negative AGC voltage therefore allows the r.f. and i.f. amplifiers to operate at maximum gain—which is what is required for the weaker signals.

DELAYED AGC



As the strength of the received signals increase, however, the negative AGC voltage becomes progressively more effective in its opposition to the forward bias offered by the HT line, until it is sufficient to cut off all current flow through the diode. The diode then loses its delaying effect, and the AGC potential resumes control of the amplitude of the signal passing to the r.f. and i.f. amplifiers.

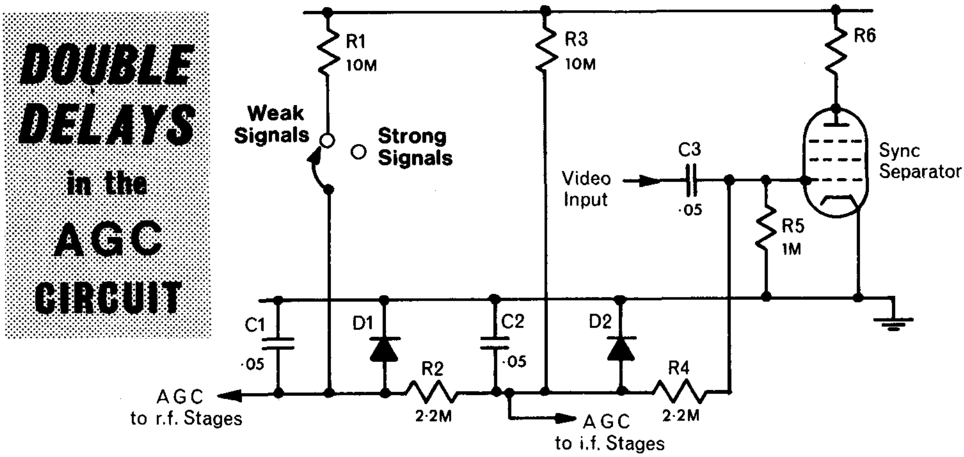
The presence of the diode serves another useful function in ensuring that the AGC line can never rise positively above zero, as it might do if no signals were present at the grid of the sync separator. Should a positive voltage ever be applied to the grids of the amplifying valves, they would at once pass larger-than-normal anode currents; and damage to themselves or their associated components could occur. In this particular role, the diode is said to function as a *clamp*.

The purpose of the potential divider R_2–R_3 at the grid of the sync separator is to attenuate the AGC voltage before it is applied to the stages whose gain is to be controlled. The point of this is that the amplitude of the AGC voltage created at the grid of the sync separator is often too great to be fed direct to the valves to be controlled. This is particularly so in the case of modern high-gain (high slope) valves which have a restricted grid base, and are therefore capable of accommodating only small changes in the amplitude of signals reaching their grids.

Double-delayed AGC

The maintenance of a good signal-to-noise ratio within a TV receiver makes it important that the r.f. stages—in particular, the mixer stage in the tuner—should be operated at a fairly high level of signal. For this reason, it is usual in a modern TV receiver to provide a second delay in the AGC circuit, operating for some time after the first one has ceased to be effective.

The first delay is generally introduced into the circuit immediately after the point at which the AGC voltage is produced, as you have just seen. The second is interposed between the first delay and the r.f. amplifying stages. The simplified arrangement shown in the illustration works as follows.



Say that a signal is being received which is *just* sufficient to overcome the delay potential offered by the diode D_2. A negative AGC potential is built up as this happens, and appears across the capacitor C_2 (C_2 and R_4 forming the integration circuit already described). A negative AGC potential is applied to the i.f. stages, thereby reducing their gains.

The same AGC potential now has to overcome a similar delay potential offered by D_1 (the purpose of R_2 is to isolate Delay 1 from Delay 2). Until this is achieved, the i.f. stages only are reduced in gain and the r.f. stages are permitted to operate at maximum gain. But should the strength of the received signal continue to increase, the AGC potential developed across C_2 will eventually become large enough to overcome the delay offered by D_1 also. A negative AGC potential will be built up across C_1 and applied to the r.f. stages, reducing their gain accordingly.

Should the strength of the received signal now fall, AGC will be removed from the r.f. stages first, and only if it continues to fall further, from the i.f. stages as well.

When two AGC delays are employed, it is common practice to provide means of rendering the second delay inoperative in case the receiver is to operate in an area of very high signal. This is generally effected by a wire-and-plug arrangement set by a TV dealer—the second delay being effectively removed altogether by disconnecting its anode resistor R_1 from the HT supply. This causes r.f. gain to be reduced at the same time as i.f. gain is reduced.

If, however, the receiver is to be used in a fringe area where much higher r.f. gain is required, the delay is re-connected into circuit by again connecting the diode load to the HT supply.

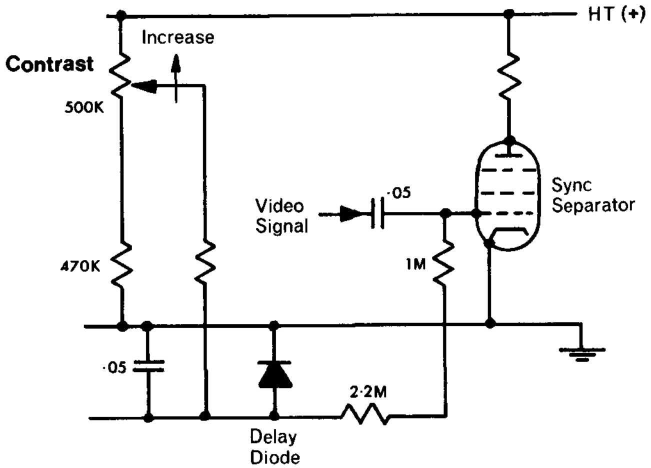
The Contrast Control

A component which in many less expensive TV receivers is incorporated in the mean-level vision AGC circuitry is the contrast control. It takes the form of a potentiometer (typically, of some 500 k) connected between HT(+) and the anode of the delay diode (or, if there are two such diodes, of the first of them). The slider of this potentiometer is activated by the viewer manipulating the *Contrast* control knob on the outside of his receiver.

You know that the upper limit of the signal reaching the Video Amplifier is determined by the value(s) of the potential(s) on the delay diode(s) in the AGC circuit. Once the incoming signal starts to exceed this value, the AGC control potential increases in proportion, and immediately reduces the gain of the r.f. and vision i.f. stages to compensate for the attempted rise in signal amplitude.

If, then, the AGC delay potential is increased (made more positive), the incoming signal will be allowed to reach a higher level before it triggers off AGC action. This means that a larger video signal will be applied to the picture tube, and there will therefore be an increase in the contrast of the picture being displayed. Conversely, if the delay potential is reduced, AGC action will be initiated at a lower signal amplitude, a smaller video signal will be applied to the picture tube, and the contrast of the picture will be reduced.

It follows that a simple method of allowing the viewer to control picture contrast is to enable him to adjust at will the positive voltage applied to the (first) delay diode. In the circuit illustrated below, contrast will be increased (*i.e.*, video signal will be made larger) as the slider on the potentiometer is moved *towards HT*(+), thus making the voltage applied to the diode *more positive*



Disadvantages of this type of AGC contrast control are, first, that it affects the amplitude of the video signal fed to the video amplifier, and therefore that of the signal fed to the sync separator. This means that it could in certain circumstances impair picture synchronisation. A second disadvantage is that, in varying the gain of the r.f. stages, the contrast control also varies the amplitude of the signal fed to the sound i.f. stages. If the sound AGC circuit is unable to accommodate these variations, the *Volume* control will have to be adjusted every time the *Contrast* control is used.

The Contrast Control (*continued*)

Neither of these disadvantages, of course, applies to the high-level type of contrast control which you learnt about in Section 15 on the Video Amplifier. This control in no way affects either the r.f. or the i.f. gain of the receiver, but operates (you will recall) to maintain the video signal at a near-constant amplitude at the point where it is applied to the grid of the sync separator. This method of achieving contrast control is, however, more expensive than is the simpler, though less efficient, method just described.

Note that in some receivers an internal preset "sensitivity" control may be found incorporated into the tuner, to set the maximum gain of the receiver. This type of control is particularly useful in areas of high signal strength to "take the weight off" the AGC circuits and to ensure that they are always operating within the range they can handle.

A more general point about contrast controls is perhaps worth making. Since any control capable of varying the gain of either the r.f. or the vision i.f. amplifying stages will automatically affect the amplitude of the video signal applied to the picture tube (and hence the tonal contrast of the reproduced picture), it would seem at first sight that the contrast control circuitry could be put almost anywhere in the video or vision sections of the receiver. This is not so, however, because if such a control were used, *e.g.*, to control the gain of the mixer stage in the tuner, both the vision and sound AGC circuits would react immediately to every variation of the control by trying their best to maintain the amplitude of the incoming signal *constant*. Since no AGC circuit can distinguish between wanted and unwanted variations in the signal reaching it, any form of contrast control which affects the gain of the r.f. or i.f. stages of the receiver must either work in conjunction with the AGC circuits or else be situated at a point in the circuit *after* the r.f./i.f. stages have done their work. This latter, of course, is the case with the efficient high-level contrast control situated in the Video Amplifier.

Mean-level AGC—A Typical Circuit

The illustration on the opposite page shows the essential components of a mean-level vision AGC circuit for a modern TV receiver (it is, in fact, the Baird 620). It will be seen that the AGC potential is here derived directly from the anode of the video amplifier instead of from the grid of the sync separator; and also that the "diode action" typical of the grid and cathode electrodes of the sync separator valve is performed instead by a separate triode connected to function as a diode, with its anode and grid electrodes strapped together. This valve is labelled V_1(B) and forms the triode section of a triode-pentode multiple valve.

The video waveform at the anode of the VA is coupled to the anode/grid of V_1(B) through C_3, which removes the d.c. component of the waveform and converts it into a fully a.c. wave having a mean value of zero. V_1(B) then rectifies this a.c. wave, so producing a truly negative d.c. level just as did the grid and cathode of the sync separator in the illustration on page 3.4.

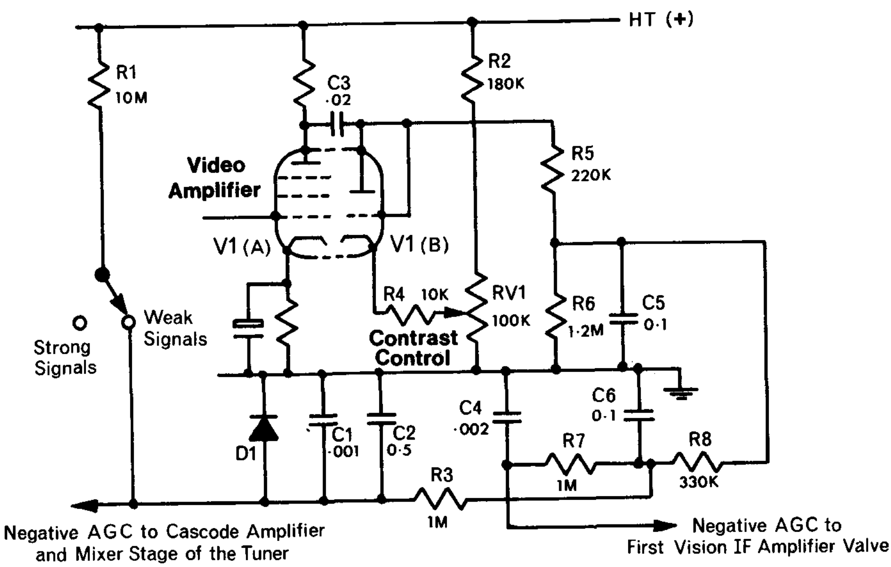
The resultant negative half-cycles are first smoothed by C_5 and the resistive attenuator formed by R_5 and R_6, and then additionally smoothed by C_6 and R_8. A negative AGC potential is then applied to the first vision i.f. amplifier via R_7; C_4 is an r.f. decoupling capacitor for the grid circuit of this valve.

Mean-level AGC—A Typical Circuit (*continued*)

The potential developed across C_6 is also applied, via R_3, C_1 and C_2, to the tuner, where it is used as a gain-controlling voltage in the cascode amplifier and mixer stages. R_3, C_1 and C_2 act as additional smoothing and r.f. decoupling components, with C_1 (a low-inductance capacitor) offering better r.f. filtration than C_2.

The circuit shown is of the double-delay type, the first delay being formed by varying the reverse bias applied to the rectifying "diode" V_1(B). This is done by varying the positive potential applied to the cathode of the "diode", the control which does this (RV_1) also acting as a contrast control. As the slider of this control is moved further and further up towards the HT(+) line, so fewer and fewer of the positive half-cycles of the video waveform are rectified, and so the mean value of the wave applied to R_5, R_6 and C_5 becomes more positive (=*less negative*). The valves controlled by this waveform in the vision i.f. amplifier and the tuner are thus allowed to pass more current, and a greater amplitude of video waveform is applied to the picture tube.

The second delay is formed by the semiconductor diode D_1 and its anode load R_1, with R_1 being switched into the circuit (by the retailer, not the viewer) if signal strength in the reception area where the receiver is to be used is below average.



A Typical* MEAN-LEVEL AGC *Circuit

Mean-level AGC—Blocking

A serious drawback of mean-level AGC is its susceptibility to a phenomenon called *blocking*. Blocking occurs when the AGC voltage is unable to respond quickly enough to counteract the sudden appearance of a very strong signal (such as might occur when the viewer switches channels). It is the suddenness of the signal's appearance which causes the trouble, for if an equivalent change in signal strength were to be applied over a longer period of time, the AGC would have no difficulty in following the change and reducing the gain of the receiver appropriately.

Blocking occurs in the following way. Imagine that a very strong signal is suddenly applied to a receiver which has been operating at high gain from a much smaller signal. Because of the long integration time of the AGC circuit (typically, 200 ms), it will be unable immediately to deal with the new signal, and a large-amplitude signal will be applied to the grid of the final vision i.f. amplifier. This valve promptly overloads, and its anode current rises to near-saturation. Anode potential "bottoms", with the result that a signal of near-constant amplitude is supplied to the vision detector. The detector, in turn, produces an abnormally large positive-going signal of near-constant amplitude, and applies this to the video amplifier—which promptly overloads also and stays in this condition for the duration of its input signal.

The output from the VA during its overloaded condition is, of course, at near-bottoming potential and contains little video information. This means that a meaningless picture appears on the picture tube and, even more important, that a near-d.c. waveform is applied to the anode of the "diode" V_1(B) in the illustration on the last page. This means that there is no signal to be rectified (for a coupling capacitor will not pass d.c.), and therefore that no negative AGC voltage will be created to counteract the large signal which is causing the trouble. Nothing can alter this state of affairs until the receiver is switched OFF.

In practice, blocking can be prevented without much trouble, and with the use of very few extra components. A popular method is to connect a parallel combination of resistance and capacitance in the grid circuit of the final i.f. amplifier. This is shown in the illustration opposite, which is taken from the full circuit diagram of the Dual-Standard I.F. Amplifier A appearing on page 2.99, the same component numbering being used in both diagrams.

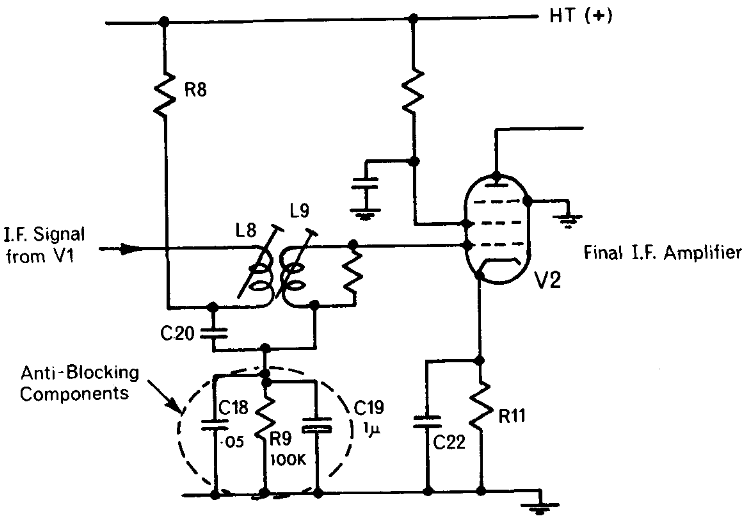
As long as the gain of the receiver is under the control of the vision AGC circuitry, the anti-blocking components C_{18}, C_{19} and R_9 have little effect. At i.f. frequencies C_{18} is appreciably less inductive than is the much larger-capacity C_{19}, and therefore presents less impedance to the i.f. signal. To this signal it therefore acts as an r.f. decoupling component, effectively short-circuiting R_9 and thereby returning the lower end of L_8 and L_9 to chassis.

When a very large signal is suddenly received, an abnormally large signal appears also at the grid of the final i.f. amplifier. The peaks of this signal cause grid current to flow, which in turn causes a negative potential to be built up across C_{19} and R_9. This biases the valve further back into the negative V_g region—with the result that less anode current flows and the valve is prevented from overloading.

Mean-level AGC—Blocking (*continued*)

With overloading prevented in this way, a less-distorted waveform will be applied to the detector, and a nearly-normal video waveform will reach the video amplifier. This near-normal waveform is passed on to the grid of the sync separator; a negative AGC potential is allowed to build up; the gain of the receiver is reduced, and fully normal operation is restored.

The action of C_{19} and R_9 is, of course, simply that of leaky-grid biasing—the time constant of C_{19}–R_9 being made quite long (100 ms in the illustration) so as to give the AGC circuit ample time to get itself into a condition in which it can handle the larger incoming signal.



ANTI-BLOCKING

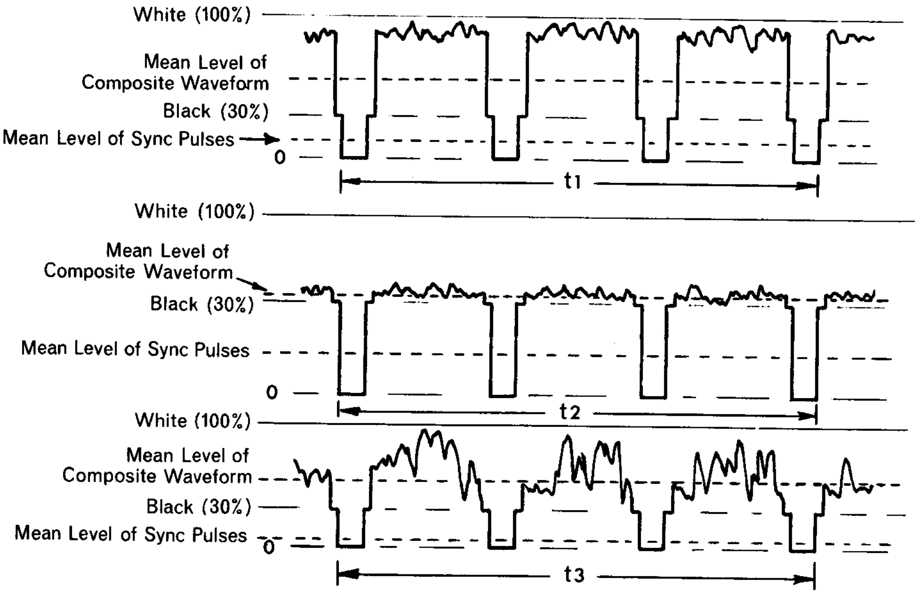
Seeking a Better AGC System

Despite its simplicity and relative cheapness, it has to be accepted that mean-level AGC is very much a "second-best" method of controlling the tonal contrast of the reproduced picture. At its best, the effect it has on the picture is rather like that which results when the video signal is a.c.-coupled to the picture tube—*i.e.*, when no true black-level reference is present at all.

The great weakness of mean-level AGC is that it depends entirely on the picture signal content of the video waveform. It is not possible to prevent the AGC potential, and hence the gain of the receiver, from varying every time the average brightness level of the scene changes, so giving rise to a picture having an almost permanently unnatural contrast. Many ingenious circuits have been designed over the years to overcome this particular failing of mean-level AGC, most of them making use of the line sync pulse to indicate the true mean level of the received signal.

The Gated AGC System

Most vision AGC systems which rely on using the mean amplitude of the line sync pulses for successful operation are grouped under the heading of *gated* AGC systems. The principle on which they work will be easily understood from the illustration below, which shows three lines (not necessarily consecutive) of a 405-line video signal inspected at three different moments of time—t_1, t_2 and t_3. Each line has a different level of mean amplitude, and a widely different picture-signal content.



Measuring the *MEAN SYNC PULSE* Level

A fact immediately obvious from the waveforms is that, although the mean level of the *complete* video waveform is indeterminate (because of the variations in picture signal content), the mean amplitude of the sync pulses is in every case clearly defined, and is completely independent of the picture signal.

Look at the three lines representing time interval t_2. The overall amplitude of the video signal has increased since t_1, as is shown by the mean level of the sync pulses. Yet the low picture-signal content has actually made the mean level of the complete waveform less than that of the three-line waveform at t_1. Clearly, any AGC system working on the mean-level of the picture signal would derive a larger AGC control voltage from the waveform at t_1 than it would from the waveform at t_2. But this would be the very opposite of what is wanted, for the *overall* (peak-to-peak) amplitude of the t_1 waveform is already lower than is that of the waveform at t_2, and so needs boosting rather than lowering.

This example shows that the amplitude of the vision signal carrier is much better determined *from the amplitude of the line sync pulses* than it is from the mean level of the picture signal itself; and you will now be looking at AGC systems working on this principle. (Note that the line sync pulses are used in preference to the field sync pulses because the much greater frequency with which the line pulses occur enable the amplitude-measuring circuits to respond more quickly to variations in amplitude.)

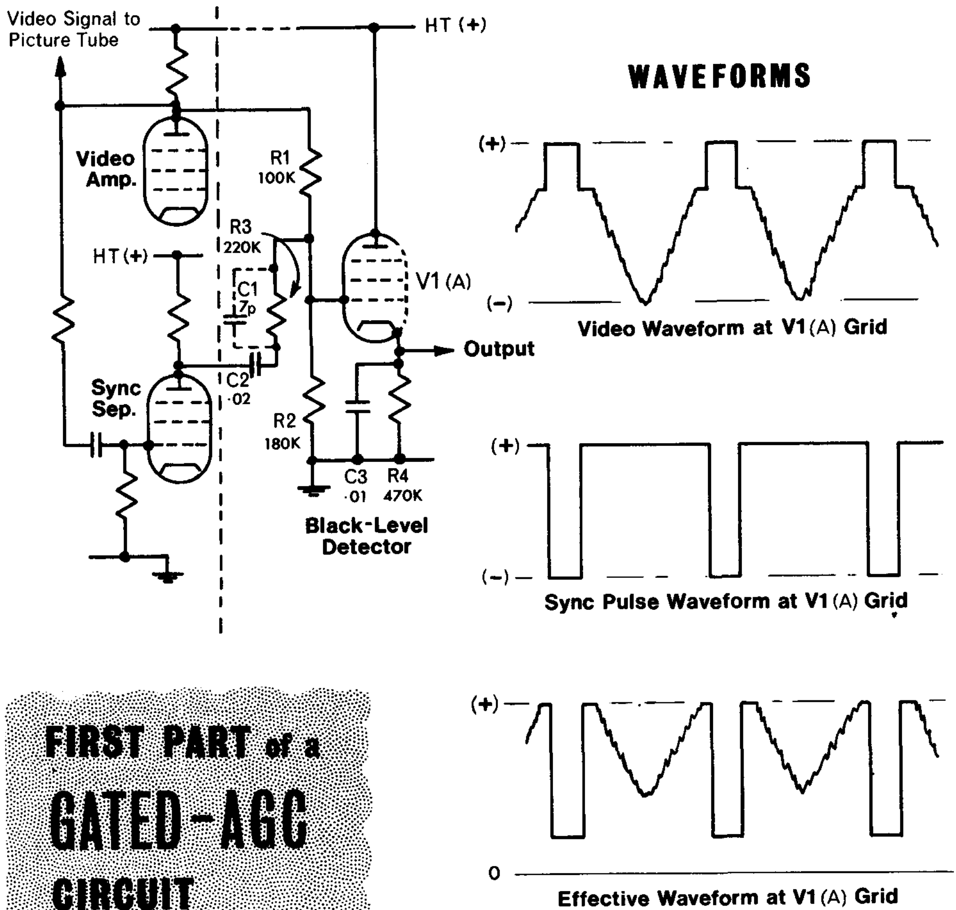
The Gated AGC System (*continued*)

In the 405-line system, video modulation of the vision carrier is positive-going (carrier amplitude *increasing* with picture brightness), and the line and field sync pulses start from a black level equivalent to about 30% modulation and extend downwards from this level until they reduce carrier amplitude to near-zero.

To measure the amplitude of the line sync pulses, it is necessary for the measurement to be made during one or other of the blanking periods which immediately precede and immediately follow every individual sync pulse—that is to say, during either the front or the back porches. Almost all sync pulse measuring circuits use the back porch period because it is considerably the longer of the two—having, you will recall, a typical duration of some 7·5 μs against the 1·75 μs of the front porch.

It is during the duration of the back porch, therefore, that the measuring circuit required must be *gated*, or made active.

The illustration below shows the essential features of the first part of a typical gated AGC circuit. (This one, as it happens, was designed by the Mullard Research Laboratories.)



FIRST PART of a GATED-AGC CIRCUIT

The Gated AGC System (*continued*)

Valve V_1(A) in the circuit on the last page is connected to operate as a cathode follower. It forms one half of a double triode (whose other half you will meet quite soon); and it has two separate input signals applied to it—one from the anode of the video amplifier and the other from that of the sync separator.

The signal from the VA is obviously the same as that which is delivered to the picture tube and to the grid of the sync separator. It is coupled to the grid of V_1(A) by the potential divider formed by R_1 and R_2—these resistors reducing the amplitude of the signal (it is about 70 V at this point) to a level within the grid base of the valve, and also providing circuit isolation.

The input signal from the anode of the sync separator consists of negative-going pulses of large amplitude, coupled to V_1(A) through C_2 and R_3, and occurring at exactly the same moments as the positive-going sync pulses in the video waveform. But the amplitude of the negative sync pulses is so much greater than the maximum amplitude attained by the positive-going sync pulses of the video waveform that these latter are effectively cancelled. The resultant waveform at V_1(A) grid is similar to that shown. The important thing about this waveform is that its most positive excursion corresponds to the black level of the video waveform—whence the name of *black-level detector* commonly applied to all that part of the circuit lying to the right of the vertical dotted line in the illustration.

The waveform appearing across R_4, the cathode load resistor of the black-level detector, would under the normal operating conditions of a cathode-follower be almost identical in size, shape and polarity to the signal present at the grid. But normal operating conditions are here modified by the presence of a 0·01 μF capacitor, C_3, connected in parallel with R_4. This capacitor, in conjunction with R_4 and the output impedance of the valve, forms an integrating circuit. As long as signal amplitude at the grid remains steady, an almost steady level of d.c. is built up across C_3. The amplitude of this d.c. level is proportional to the maximum level reached by the signal at the grid—which, as you know, occurs during the periods of the front and back porches.

But the voltage across C_3, which is required eventually to form the steady AGC potential it is desired to obtain, soon begins to leak away through R_4 between the arrival of successive sync pulses to charge it up again, and would quickly become the reverse of steady if nothing were done about it. This is where the capacitor C_1 (shown in dotted outline in the illustration on the last page) comes in. In conjunction with the parallel resistance of R_1 and R_2, C_1 forms a differentiating circuit at the grid of V_1(A) which produces a positive overshoot at the end of every sync pulse (*i.e.*, during the period of the back porch). C_3—an *integrating* capacitor—is made to charge up to the peak value of this overshoot, whose value is carefully chosen to make up for the charge leaking away during the subsequent picture signal period. Thus the voltage across C_3 is not allowed to fall below that represented by the black level of the input waveform, and an accurate AGC voltage level is maintained.

Whenever the strength of the received signal increases, a larger positive-going signal is applied to the grid of the VA, and a larger negative-going waveform appears at its anode and at the grid of V_1(A). But the reference level of this waveform (represented, of course, by the tips of the sync pulses) remains constant however great its amplitude becomes; so that the only effect of a stronger received signal is to cause the average value of the waveform at V_1(A) grid to move in a more negative direction.

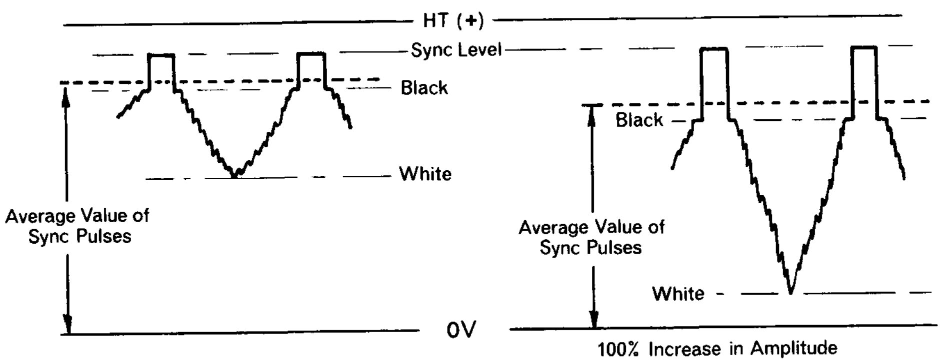
The result is a *reduction* in the voltage across C_3; and the average value of the resulting AGC voltage is lowered just when such a reduction is needed.

The Gated AGC System (*continued*)

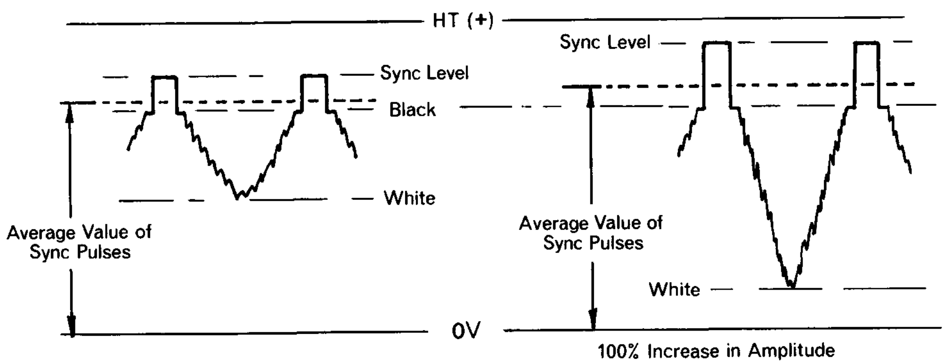
The signal developed across C_3 by the black-level detector is not yet suitable for feeding direct into the AGC line. It still requires amplification, in order to give the AGC circuitry rapid response and good gain-controlling efficiency; and it still requires a measure of d.c. restoration to ensure that its polarity is always negative with respect to chassis. At the moment, although moving in the desired sense (becoming *less positive* as vision signal amplitude increases), it is at all times positive (above zero volts) and so unsuitable for its destined AGC role.

Before seeing how this is done, however, you should first break off and consider the nature of the 625-line video signal, whose characteristics will inevitably affect the nature of any corrective circuitry through which the two signals may need to be put in a Dual-Standard Receiver.

The illustration below compares the way in which the output signal from the VA varies with changes in the amplitude of the received signal, in the two line systems. The point to note is the way in which the sync level of the 625-line signal actually becomes *more positive* when signal amplitude rises. In other words, this signal, in addition to being at all times positive with respect to chassis (which is not desired) does not even move consistently in the right sense.



405-LINE



625-LINE

The Gated AGC System (*continued*)

You know that the reason why the 625-line signal expands *in both senses* as signal amplitude increases is that the tips of the sync pulses represent 100% modulation of the vision carrier, and that peak white is only reached at 12% modulation. The system contains no zero-signal reference level at all.

The trouble is that, as the amplitude of the sync pulse tips rises with increasing signal amplitude, so must the *average* value of the sync pulses viewed as a whole. With the mean level of the sync pulses thus increasing with signal amplitude, there will be a corresponding increase in the black-level signal present at the grid of V_1(A), and a most undesirable increase in the integrated signal appearing across C_3. An AGC voltage of such a nature is worse than useless, and some form of switching is required if the same amplifier is to be used to handle the AGC signal on both line systems.

A Full Gated-AGC Circuit

A full gated-AGC circuit suitable for use in a Dual-Standard TV receiver is shown opposite. The amplifier (V_1(B)) forms the second half of a double-triode valve, of which the first half forms the black-level detector.

The input circuit of the amplifier is switched by two sections of the *Standard Selection* switch in such a way that, when the receiver is set for 405-line operation, the negative-going signal from the black-level detector is applied to the cathode of the amplifier—the grid being returned to chassis through the preset contrast control RV_2. The input signal is thus amplified without being inverted, and an amplified AGC voltage of the desired polarity is obtained.

With the receiver set for 625-line operation, the positive-going signal from the black-level detector is applied to the *grid* of the amplifier, the cathode being returned to earth through the 625-line preset contrast control RV_1. With the amplifier connected in this way, its input signal is not only amplified but also *inverted*; and the desired negative-going signal again appears at the anode.

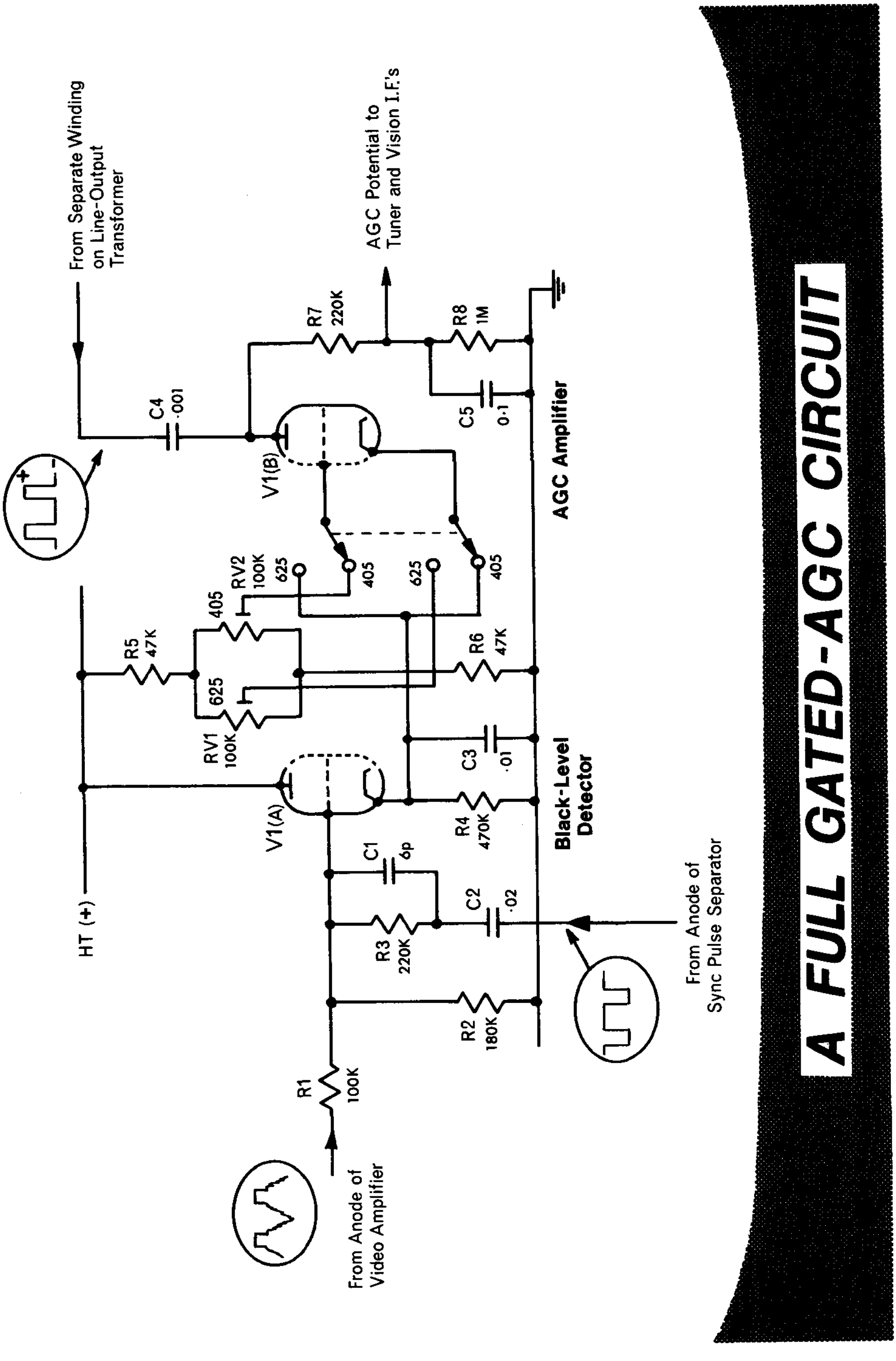
The effect of the preset contrast controls is to vary the operating bias of the amplifier, and so the threshold level which has to be exceeded by the input signal before AGC action can start. In the circuit shown, RV_1 and RV_2 are capable of being individually adjusted, and a single *Contrast* control on the outside of the receiver can be operated by the viewer to adjust to his liking the contrast of the displayed picture whichever the line standard on which his set is receiving.

The next step is to see how the AGC amplifier introduces a new d.c. level into the wholly-positive signals produced by the black-level detector V_1(A), so that they become wholly negative—and so usable for AGC purposes.

Observe an odd feature about V_1(B). It lacks the usual anode load resistor, and its anode is not returned to a positive d.c. voltage at all. It is connected instead to the separate AGC winding on the line output transformer which you read about in Section 20. Connected in this way, the valve is only capable of passing anode current at all when a positive-going pulse (of some 300 V amplitude) is applied to its anode through the capacitor C_4. Being derived from the extra winding on the line-output transformer, these pulses recur at the repetition frequency of the line-scan generator.

Whenever such a pulse is applied to C_4, the anode of the amplifier is momentarily driven positive, and the valve conducts anode current—*but only if the AGC delay potential set by the Contrast control has been overcome by the input signal from the black-level detector.* If this delay potential has not been overcome—*i.e.* if the vision signal itself has not exceeded a certain amplitude—V_1(B) anode does not conduct, and no AGC voltage is developed at all.

A Full Gated-AGC Circuit (*continued*)



A FULL GATED-AGC CIRCUIT

A Full Gated-AGC Circuit *(continued)*

The pulse arriving from the line output transformer charges C_4, and at the end of the pulse the capacitor has its upper electrode at a high positive voltage and its lower electrode at a much lower level—a little above the level of the cathode (or of the grid, whichever of them is "earthy" at the time). When the pulse ceases, the applied voltage falls to zero and the upper electrode of C_4 falls with it. C_4 cannot change its charge instantaneously, so the lower electrode also drops by the same amount (300 V). The anode of the AGC amplifier at once becomes heavily reverse-biased, and no anode current can flow.

C_4, however, begins to discharge slowly through the large-value resistor R_7. The reverse bias on the anode becomes less, and when it has dropped just enough, anode current again begins to flow—but only momentarily until another pulse from the line output transformer recharges C_4 and reverse-biases the anode once again. In this way, the anode of V_1(B) is only allowed to go positive at all during the few microseconds in which C_4 is recharging through the low resistance of the valve. Virtually the whole of the output waveform is thus of *negative* polarity.

This is, of course, nothing but the familiar action of d.c. restoration. The outcome is a negative potential developed at the anode, almost steady save for the brief upward excursions while the valve briefly conducts during the period of the anode pulses. These upward fluctuations are attenuated by the potential divider formed by R_7–R_8, and smoothed by the integration circuit R_8–C_5. A very steady negative AGC potential is thus developed across C_5, fully suitable for controlling the gains of the tuner and vision i.f. stages.

This AGC voltage, of course, varies in amplitude in proportion to the amount of anode current caused to flow, during the short duration of the anode pulses, by the signal applied to its grid (625-line system) or to its cathode (405-line) respectively. When a sharp increase in signal amplitude occurs, the AGC voltage is driven even more negative. It continues at that polarity for exactly as long as the signal remains abnormally strong. Thus the stronger the signal, the larger the negative AGC control voltage applied as grid bias to the earlier stages of the receiver, and the smaller become their respective gains—until the adverse effects of the suddenly increased value of the received signal have been wholly overcome.

Advantages of the gated type of AGC circuit include freedom from the "blocking" paralysis to which the type of circuit working on mean signal level is prone. This immunity is due to the d.c. coupling between the anode of the VA and the grid of the black-level detector, and to the absence of long time-constants.

Another advantage is flexibility—in that, though the positive pulses applied through the capacitor C_4 to the anode of the AGC amplifier are usually in synchronism with the sync pulses of the received signal, they do not have to be; and their repetition rate is in practice immaterial.

Lastly, the system is very efficient, because the degree of amplification applied to the signal from the black-level detector is sufficient to allow quite large changes in the amplitude of the received vision signal to occur without causing more than minor variations in the amplitude of the resulting video signal.

AGC delay diodes are used in gated AGC systems in the same way, and for the same purposes, as they are in mean-level ones.

REVIEW of Automatic Gain Control

The purpose of AGC in a TV receiver is to maintain the sound and video signals constant at a predetermined level set by the *Volume* and *Contrast* controls on the outside of the chassis, whatever variations may occur in the strengths of either of the received r.f. carriers.

Most TV receivers have separate sound and vision AGC controls, one operating from the sound i.f. carrier, the other from the vision i.f. carrier. It is usual to arrange for the vision AGC to control the gain of any common sound and vision amplifying stages there may be (as, for instance, in the tuner) and for the sound AGC to control the gain of the sound i.f. amplifying stages only.

AGC for the Sound Carrier is required only in the 405-line system, because in the 625-line system the sound carrier is frequency modulated and is deliberately limited to a constant amplitude before it is detected. AGC for the 405-line sound carrier is derived from the d.c. level produced by the sound detector, and is applied to control the gain of the sound i.f. amplifying stages.

Mean-level AGC is the simplest, cheapest and most widely used AGC system for the vision carrier, but not the best. In it, the amplitude of the vision carrier is estimated by measuring the mean amplitude of its video modulation. This is done by taking the fluctuating d.c. level produced by leaky-grid action at the grid of the sync separator valve, and smoothing it by means of a simple C–R circuit.

The reason why this method is inaccurate is because a strong signal having little picture-signal content (and therefore representing a dark scene) will produce a weaker AGC voltage than will a much less strong signal having a large picture-signal content; and *vice versa*. The AGC voltage is therefore dependent on the tonal composition of the transmitted scene rather than on the actual strength of the received signal.

Gated AGC systems determine the amplitude of the vision signal carrier from the amplitude of the line sync pulses, rather than from the mean level of the picture signal itself. Though more complicated and expensive, this method of determining the level of signal at which AGC needs to be applied is much more accurate, and produces a steadier control of contrast in the picture appearing on the screen.

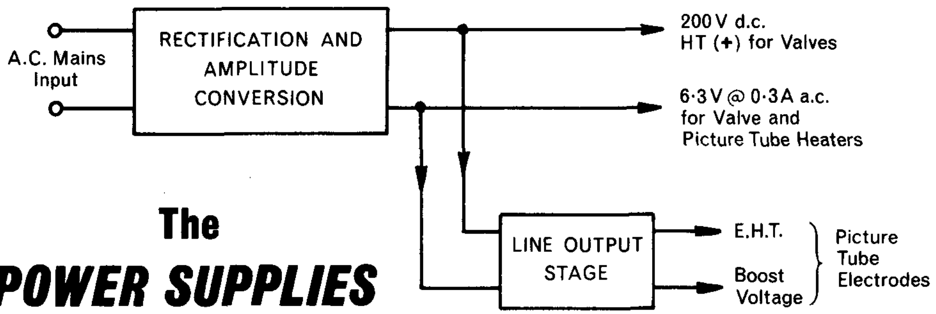
Delayed AGC is used to prevent any control of gain being applied until the received signal is strong enough to overcome a preset threshold. The result is to stop any AGC being applied when weak signals are being received. The AGC threshold which causes this delay is produced by a voltage developed across a forward-biased diode.

Double-delayed AGC employs two separate delay diodes, one operating after the other. The second delay allows the early stages of the receiver to operate at fairly high gain to ensure a high signal-to-noise ratio, but restricts the gain of these stages whenever signal strength becomes excessive.

§24: POWER SUPPLIES

All valve-type TV receivers operated from the mains have two requirements for *primary* power supplies: (*a*) a high-voltage (HT(+)) supply, typically of around 200 V d.c., for the anodes of the various valves in the circuitry; and (*b*) a low-voltage (LT) supply, typically of 6·3 V at 0·3 A, a.c., for the heaters of the valves and of the picture tube.

The main *secondary* voltages required are the EHT and boost voltages needed for the electrodes of the picture tube. You have already seen in Section 20 how these two voltages are generated in the line scan output stage, which is itself powered in the first place from the HT(+) and LT supplies. This type of derived voltage will therefore not be described again, though they are shown schematically in the block diagram below.



The *POWER SUPPLIES* for a *TV Receiver*

Other operating voltages, such as those required for screen grid electrodes and for grid bias and reference potentials, are usually derived from potential divider networks connected across the HT(+) supply, or from valve-operating currents flowing through small-value resistances.

The power consumed by a typical 19″ TV receiver from a 240 V mains supply is of the order of 180 W—which is not much more than the power consumed by the electric lamp which you would normally be using to light the sitting room.

The Mains Supply

Although thousands of receivers are still in use which were designed to work on the earlier mains voltages ranging from 200 V to 240 V, the domestic a.c. main supply in Britain is now standardised at 240 V, 50 Hz. It is conveyed on a three-wire system. Two of these wires, designated **Live** and **Neutral**, carry the 240 V between them. The third is a protective **Earth** wire which is usually connected to ground where the supply enters the house. The Neutral wire, though not directly earthed, is normally at near-earth potential, whereas the Live wire carries the full 240 V.

Until a few years ago, the standard colour coding for British mains wiring was *Red* for the *Live* wire, *Black* (or *Blue*) for the *Neutral* wire, and *Green* for the *Earth* wire. But recent international agreement has resulted in a new standard colour code which is **Brown** for the **Live** wire, **Blue** for the **Neutral** wire and **Green and Yellow** for the **Earth** wire. All modern TV receivers are being wired in accordance with this convention, although only the Live and Neutral wires will probably be used (you will see why this is so shortly).

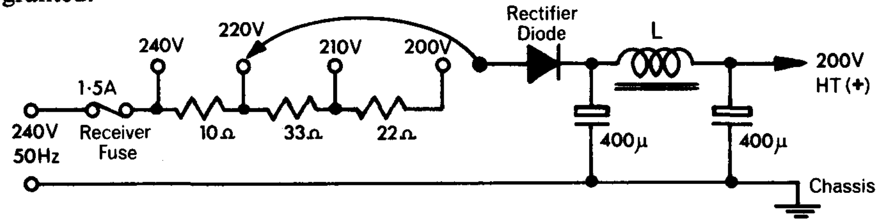
The HT Supply

The 200 V required for the HT(+) supply, being quite close in value to the value of the a.c. mains supply itself, is usually obtained through a simple half-wave rectifier circuit connected directly to the mains, very similar to the circuit described in *Basic Electronics,* page 1.18. The rectifier may be either of the metal type or it may be a diode valve. In the more modern TV receivers, it will more likely be a semiconductor diode.

The big advantage of this method of producing the HT voltage is circuit simplicity and low cost. The big disadvantage is that the Neutral lead from the mains has to be connected directly to the receiver chassis—which, in turn, means that the chassis must be isolated from the viewer. The reason for this is a bit involved. Since the chassis cannot be directly connected to earth, there is no need to equip it with a third (Earth) wire, and it is therefore usual to connect it to the mains by means of a simple (and cheap) two-pin connector. Unfortunately, most connectors of this type are capable of being plugged into the wall socket either way round—which means that it is possible for the chassis of the receiver itself to become "live".

This is of no particular significance as far as the receiver itself is concerned, but it could be a potentially serious hazard for the viewer if he should accidentally touch a metallic part of the chassis. It is as a partial safeguard against this risk that control knobs are usually of the push-on type, instead of being secured by metal screws, and that the loudspeaker grille is frequently made of non-conducting fabric or plastic. Other precautions are taken to ensure that all accessible metal parts are well insulated from the chassis.

The use of a 3-pin mains connector, even though its Earth pin remained unused, would prevent the accidental reversal of the mains supply to the receiver, and is for this reason to be recommended. But even this method of connection relies on the wiring within the mains plug being correct—something which the viewer should never take for granted.



Half-Wave Rectification of the HT Supply

The illustration shows a typical half-wave rectifier circuit, with *LC* smoothing, such as might be found in a 19″ receiver. The three resistors connected in series with the diode enable the receiver to operate from mains supply voltages over the full range 200–240 V. When a 240 V supply is applied, all the resistors are used and the output voltage from the diode is reduced to the desired 200 V. When a 200 V supply is applied, none of the resistors is used. Intermediate supply voltages call for the use of intermediate values of resistance.

These resistors are called *dropping* resistors and are usually constructed as a single high-wattage resistor tapped at intervals along the length of the wire from which it is made to provide the individual resistance values required. The same resistance unit is used to provide similar, but separate, dropping resistors for the valve heater supplies, as you will see in a moment.

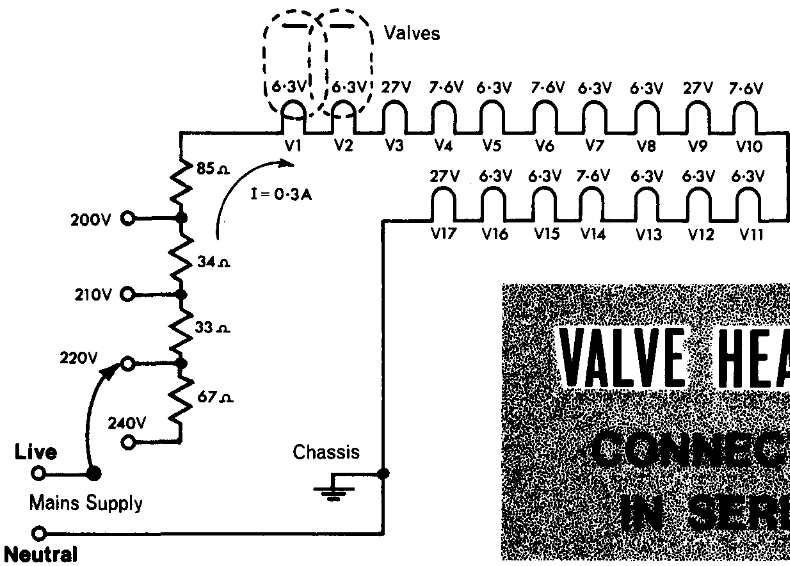
The LT Supply

Most of the valves used in any TV receiver require operating voltages of some 6 or 7 volts for their heaters, but several require somewhat higher voltages than this. A theoretically practical way of providing such voltages would be to use a small heater transformer producing the desired heater voltage and operated directly from the mains supply. Such an arrangement, however, presupposes that every valve used in the receiver operates at the same heater voltage, and that a.c. mains supply is always available. Since this is not always the case, something more flexible is required.

A simple and cheap method of producing the required heater power is to connect all the heaters in series and then to connect the whole chain across the mains supply through any additional resistance which may be required. This method is used in all British receivers. Clearly, since all the heaters are in series, they must all be supplied with the same operating *current*, which means that valves operated in this way must be designed to operate at a standardised heater current. This standardised heater current is 300 mA (0·3 A). It remains constant even for valves whose operating *voltage* requirements are different.

Consider, for example, a receiver containing 17 valves, ten of which require heater voltages of 6·3 V, four of 7·6 V and three of 27 V. All operate from a heater current of 0·3 A. The total voltage which needs to be connected across such a series chain is: $(10 \times 6{\cdot}3\text{ V}) + (4 \times 7{\cdot}6\text{ V}) + (3 \times 27\text{ V}) = 174{\cdot}4\text{ V}$. With the chain connected across a mains supply of 240 V, an additional resistance must be added of a value such that, when the chain is passing 0·3 A current, it will "drop" the excess voltage. This excess voltage is obviously $(240\text{ V} - 174{\cdot}4\text{ V} =)$ 65·6 V; and the value of the resistance needed to drop such a voltage with this current is determined by Ohm's law. $R = 65{\cdot}6\text{ V} \div 0{\cdot}3\text{ A}$, which works out at about 219 ohms.

The illustration below shows how the heaters in the example quoted are connected to the mains supply. Verify, by Ohm's law, that the resistor values shown as being encountered by the electrons entering the circuit from the mains are those required to drop the excess voltage if the mains voltage is 240 V, 220 V, 210 V or 200 V respectively.



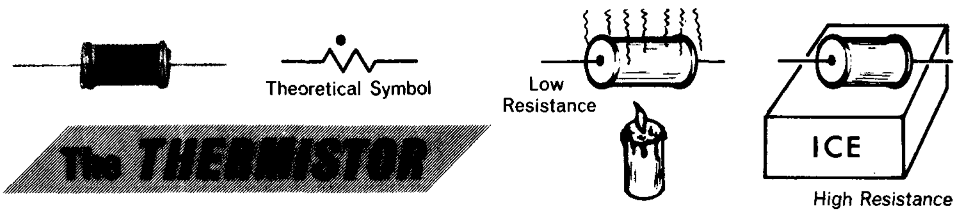
VALVE HEATERS CONNECTED IN SERIES

The LT Supply *(continued)*

The heater element of a valve is very like the filament of an ordinary electric lamp. Its resistance when cold is low; but by the time it has reached normal operating temperature (which is red hot), this resistance has become comparatively high. So if a series-connected chain of cold heater elements were suddenly switched across the mains supply, the low initial resistance of the chain would allow an enormous surge of current to flow—more than enough to "blow" the fuse in the receiver. This is prevented in practice by connecting in series with the chain a temperature-dependent resistor called a *thermistor* (a name derived from the words "thermal resistor"), such as you have already met in Section 20.

A typical thermistor may have a resistance when cold of nearly 4,000 ohms; but this resistance, when the thermistor is hot and passing 0·3 A, may drop to as low as 50 ohms. With such a resistance connected in series with the heater chain, the "switch-on" heater current is limited to a safe value of under 60 mA, given a mains voltage of 240 V. As the thermistor warms up, its resistance becomes progressively less, and more heater current is allowed to flow; the process continues until both thermistor and valve heaters reach an equilibrium temperature at which the desired heater current of 0·3 A flows. Allowing the heaters to warm up gradually in this way does much to prolong their useful life.

The physical appearance of a typical thermistor is shown below. It is some 20 mm long, with a diameter of about 10 mm. Note, however, that there exist a great variety of thermistors of all shapes and sizes, their dimensions depending on their intended use and the design preference of their manufacturers.



The HT and LT Supplies—Circuit Diagram

The complete circuit of an HT/LT power supply for a typical valve-type TV receiver (it is in fact Baird Model M.620, and its circuit diagram is given by courtesy of Radio Rentals Ltd) is shown in the illustration overleaf. The mains voltage adjustment resistors are, as you know, manufactured as a single unit, and enable the receiver to operate over the voltage range 200 V to 250 V. HT adjustment is made (for ease of identification) through the two Red leads, and LT adjustment through the two Brown leads.

The several capacitors shown are there for decoupling purposes. They also help to prevent interference from the many different waveforms and frequencies present in the receiver from being conveyed to other parts of the circuit by way of the heater chain.

The UHF tuner, of course, presents a special case because of the very high frequencies involved; and small r.f. chokes are included in its heater circuit with the object of suppressing any interference which may arise at this point.

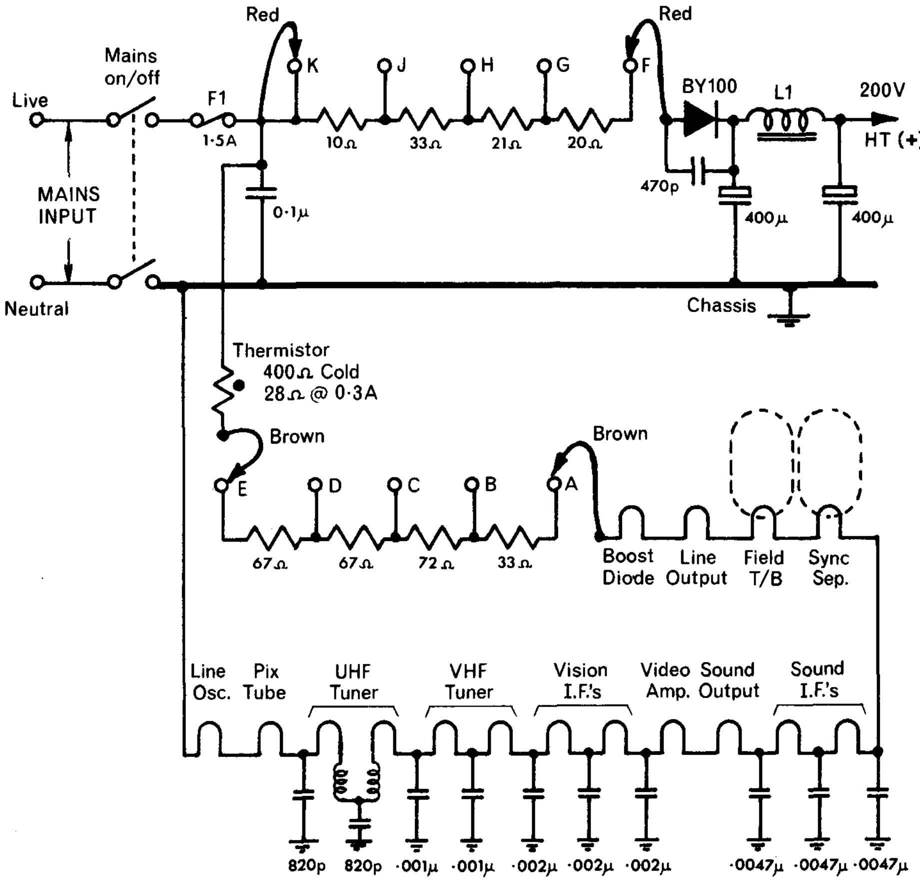
The danger of creating interference is also a reason for positioning the heater of the line oscillator stage (see circuit diagram) at the remote, or earthy, end of the chain, whence it is harder for the line oscillator waveform to reach the more sensitive stages of the receiver.

The LT and HT Supplies—Circuit Diagram (*continued*)

Another reason for situating certain heaters at the earthy end of the chain is to keep the heater-to-cathode potentials of certain valves as low as possible, so minimising the possibility of heater-to-cathode breakdown.

This is the reason why the picture-tube heater itself is placed almost at the end of the chain. You will recall that the cathode of this tube is connected to the anode of the video amplifier, and is therefore normally held at a high positive potential. If the heater of the picture tube were to be connected in the high-voltage end of the chain, a very high potential difference between the heater and cathode would be created every time the mains voltage passed through its negative half-cycle.

Such a potential could easily cause the eventual breakdown of the heater-to-cathode insulation, resulting in a highly undesirable short-circuit being created between these two electrodes of a very expensive component of the TV receiver.



The HT and LT POWER SUPPLIES

Circuit Diagram

§25: FAULT-FINDING IN THE TV RECEIVER

Efficient fault-finding in a TV receiver is a matter of applied logic, just as it is in the case of a motor-car or any other complex piece of equipment which relies for its successful operation on the correct functioning of several separate stages. It is true that an experienced TV serviceman or garage mechanic, long familiar with the make of receiver or car brought in to him for attention, can often put his finger on the cause of the trouble without going through any recognisably logical mental process at all. It is simply that he has seen or heard that particular symptom or collection of symptoms before, and so can make an experienced guess as to which particular component in which particular stage of the mechanism is causing the trouble—and he can often do this without having much in the way of theoretical understanding of how the mechanism works.

But the key word in that sentence is "experienced", and the experienced TV serviceman is not likely to learn much from reading this particular Section of *Basic Television* anyway. For the trainee repairman, however, and for the "do-it-yourself" enthusiast wishing to learn how to maintain his own set, there is no substitute for a more disciplined approach. This approach must begin with an exact definition of the symptoms displayed by the faulty equipment, followed by logical analysis based on the TV theory covered in this series, until the particular stage in the equipment in which the fault is located has been identified by a process amounting to *a rational elimination of the impossible.*

The first rule in fault-finding, therefore, is to **define the symptoms.** Even the home-repairman will find the rule helpful in getting himself started off straight in the process of rational deduction which must follow; but for the serviceman confronted with a strange set which he is simply told "won't work", it is an essential beginning. Start by asking yourself or your customer whether it's the sound or the vision that's giving trouble, and say you get the answer, "There's no sound". "Ah! But the picture's all right, on all channels?" you ask. "Oh yes, that's fine." "Good. Is the sound missing on all channels?" "No, only on the 405-line ones. . . ." Already you've got a long way, but ram it home with, "I see. So there's nothing wrong on the 625-line channels, but the sound is missing from all the 405-line channels even though the picture on these channels is OK?" "Yes, that's right."

What you have done is to define the fault so that you know exactly what your customer is complaining about. The fact that (as you may well find out later on) the picture is wishy-washy and the tube ought to have been replaced years ago has nothing to do with the fault you are looking for. Your customer is quite happy with the picture he is getting, bad as it is. All he wants is the sound to go with it. Anything else you can do to improve the performance of his set will be merely a bonus—hopefully to both of you.

The next rule is simple. Switch on and **verify** that what the customer thinks has gone wrong is in fact what *has* gone wrong. In the process you may well spot other symptoms which will help you in the coming diagnosis.

Now start thinking, and as a first step **eliminate the impossible.** In the case in question, there can be nothing wrong with the loudspeaker, or with the amplifier feeding it; for otherwise it would not have worked when the receiver was set for 625 lines. And since the fault persists on all the 405 channels but does not affect the corresponding pictures, it is unlikely to lie in the tuner or in any of the common sound and vision i.f. stages. At once you know you are looking for a stage which is common to all 405-line channels, but which affects the sound signal only and which forms no part of the audio-frequency amplifying stages. . . .

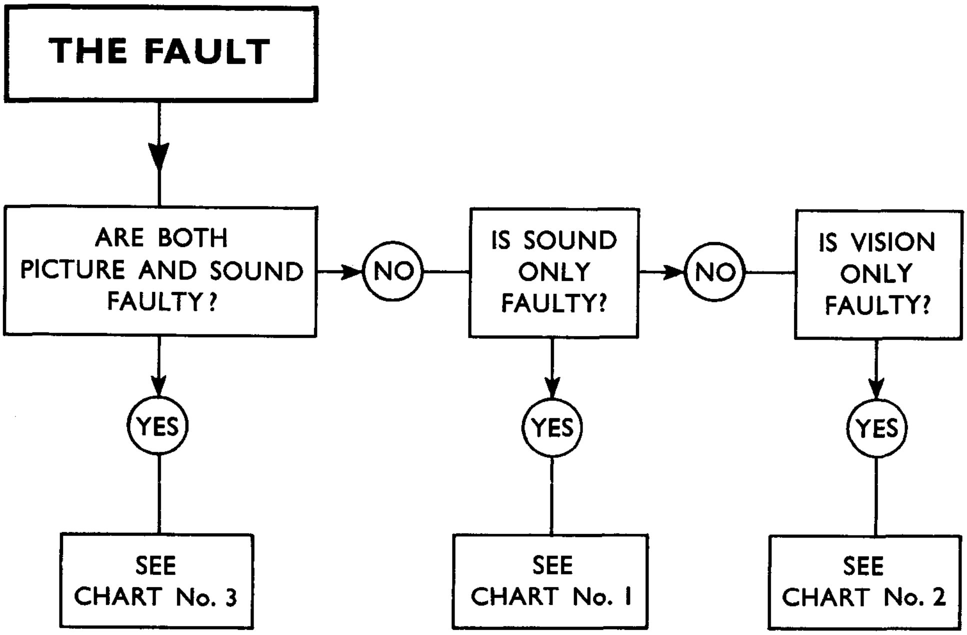
Logical Analysis of the Symptoms

Well, it shouldn't take you long now to deduce that the trouble must lie somewhere between the sound i.f. stage and the sound detector, and that is where you start looking. The fault itself may be in the detector diode or in one of the components associated with it, or it may be a faulty section of the Standard Selection switch. These are things which you will have to determine by a process of trial-and-error. But you will have enormously cut down this process by careful identification and verification of the exact nature of the symptoms displayed, and by a couple of minutes' rigorous analysis of what could possibly have caused them.

Logical analysis of the symptoms displayed is thus the basis of all successful fault location, just as it is of any good medical diagnosis. The next few pages will accordingly be devoted to a general approach to the problem on these lines, followed by a brief look at a dozen of the more common symptoms and the best way of rectifying them.

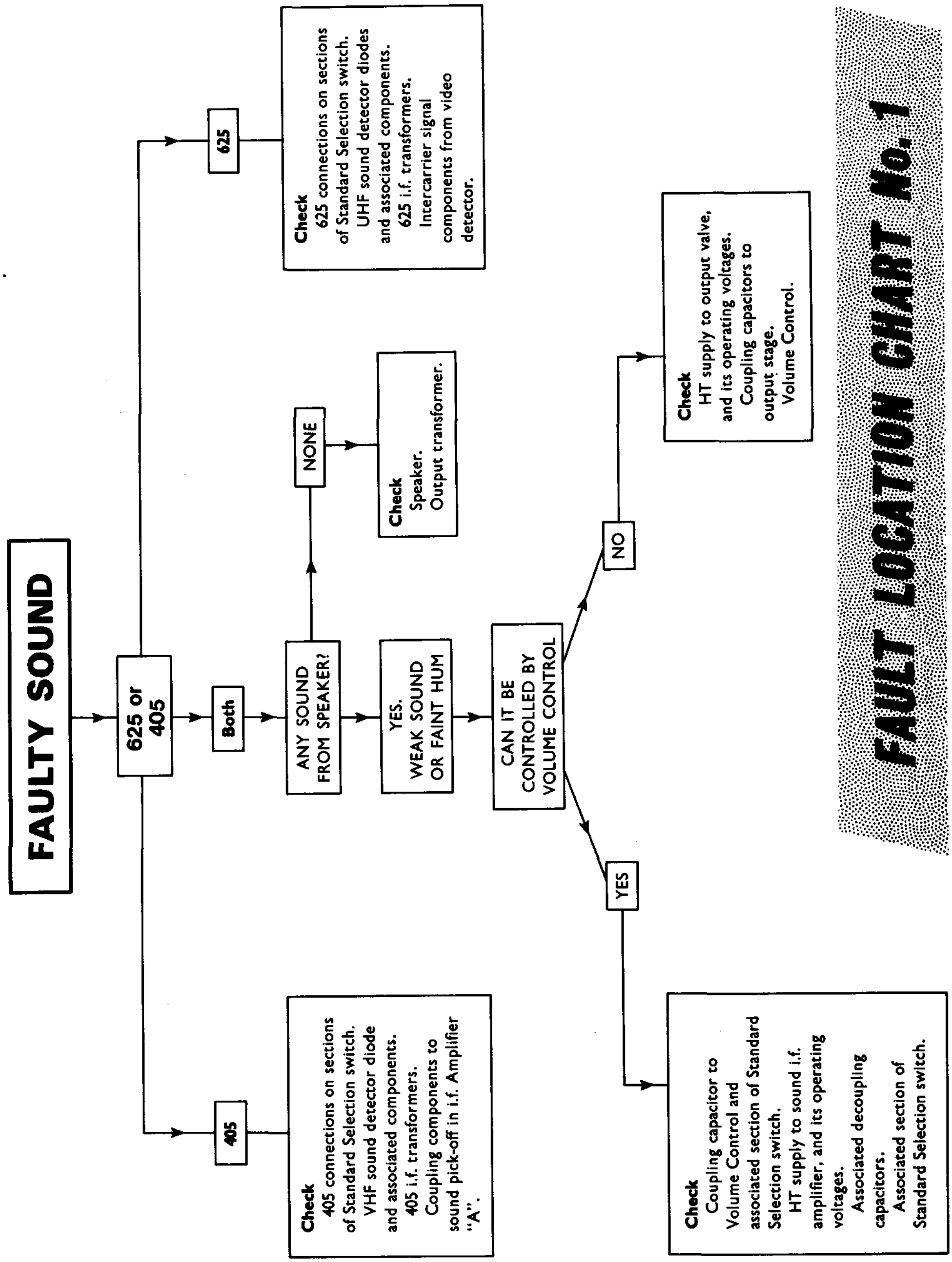
Fault-location Charts

Featured on the next few pages are three fault-location charts, to which the block diagram below acts as a key. Answer the questions posed on this key, and you will be directed to the particular chart you need. Note that, in the key and in the charts alike, whenever the answer to a particular question is **Yes**, you are directed *down* the page to the next question; whenever it is **No**, you are directed *across* the page either to the left or to the right.



All the charts have obviously had to be simplified, in that they cannot hope to cover every one of the wide variety of faults and symptoms likely to be encountered in practice. But they provide a very useful introduction to correct fault-finding procedure, and in most cases will guide you pretty directly to the "suspect" stage of the receiver at which a more detailed examination should begin.

Faulty Sound



Faulty Sound

Fault Location Chart No. 1 is based on the fact that in the Dual-Standard Receiver faulty sound can occur either on one standard or on the other, or on both of them together. Alternatively it may occur on one only of the available 405 channels.

Take the case where sound is missing on both standards, and assume that a faint sound (it is probably a 50 Hz mains hum) can be heard when the ear is placed close to the speaker. Assume, further, that the volume of this faint sound is unaltered when the Volume Control is operated.

The chart tells you that the fault probably lies within the circuitry associated with the sound output stage, and that the sound output valve needs checking. This can be done either by connecting it to a valve-tester, if you have got one, or by temporary replacement by another suitable valve known to be operational.

You are also advised to check the operating potentials of this sound output valve, and the value of the HT supply to it. While you are doing this, it is good practice to look around for signs of overheated or burnt-out resistors. Overheating can occur if a grid coupling capacitor goes short-circuit or develops a low internal resistance, thereby causing the valve to pass an enormous overload current. (This is always potentially liable to happen, you will recall, because of the positive voltage applied to the grid of the valve from the anode of the preceding stage.)

Lastly, you are advised to check the operation of the Volume Control itself, lest the valuable evidence provided by the fact that it doesn't cure or alleviate the fault when it is operated should itself prove unreliable. If operation of the Volume Control *does* mitigate the symptoms, it is obvious that the fault must lie somewhere in the circuitry earlier than the point at which the Volume Control exerts its effect.

Faulty Vision

The number of things which can go wrong with what appears on the screen of a TV receiver is formidably large—whence the size and apparent complexity of Fault Location Chart No. 3 (*see pages 3.122–3.123*). It is devoted entirely to locating faults affecting the visual presentation of the received signal—whether the symptoms be loss of picture signal without impairment of the raster, or distortion of the picture signal or of the raster or of both, or even a total absence of anything appearing on the screen at all.

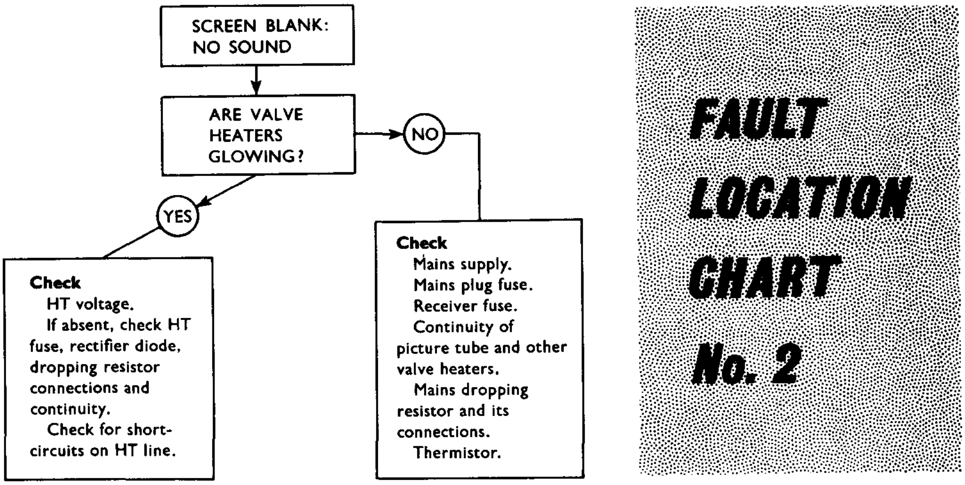
Consider, as an instance, the case where a dark horizontal band appears across the screen, but everything else about the picture is all right. On the chart you answer **Yes** seven times to the questions concerning size, linearity, brilliance, contrast and synchronisation; but the question "Is the picture free from interference?" forces the answer **No.** You are now directed to more questions to the left, where you eventually answer **Yes** to "Is there a dark horizontal band across the picture?" You are then told to check the presence of mains hum in the video circuit, because a dark bar of this type is almost always caused by a 50 Hz mains signal getting into the video feed to the picture tube. It usually does so by way of heater-to-cathode leakage (or even breakdown) in one of the valves associated with the vision signal, or by faulty decoupling in these stages.

If the *hum bar*, as it is called, is accompanied by a 50 Hz sound from the speaker, the fault probably lies in one of the valves common to both sound and vision signals. If there is no such sound accompaniment, the fault must lie in a stage which handles the vision or video signals only.

Another possible cause of the hum bar type of fault is faulty decoupling of the vision AGC line, for any 50 Hz ripple not removed from this line will be fed back to every valve in the vision stages which is controlled by the AGC potential.

Screen Blank: No Sound

This fairly common fault can fortunately be located and rectified with little difficulty. As you will see from Fault Location Chart No. 2, it is usually traceable to either the a.c. or the d.c. side of the power supply circuits.



Fault-finding Hints

When you are tracing a simple fault of this kind, never be tempted to overlook the obvious. Even experienced service engineers will probably not deny that they have on occasion spent time trying to find out why no mains supply is reaching a receiver, only to discover some minutes later that it is the wiring to the mains socket on their own workbench which is faulty. The quick plugging-in of a bench-light known to be operational would have revealed this fault at once.

Another point to watch out for is the possibility that an apparently faulty valve may merely be loose in its holder. When looking for the cause of "no heaters glowing", first make sure that every valve is fitting firmly in its holder before starting out on the lengthy job of finding the one which has an open-circuit heater.

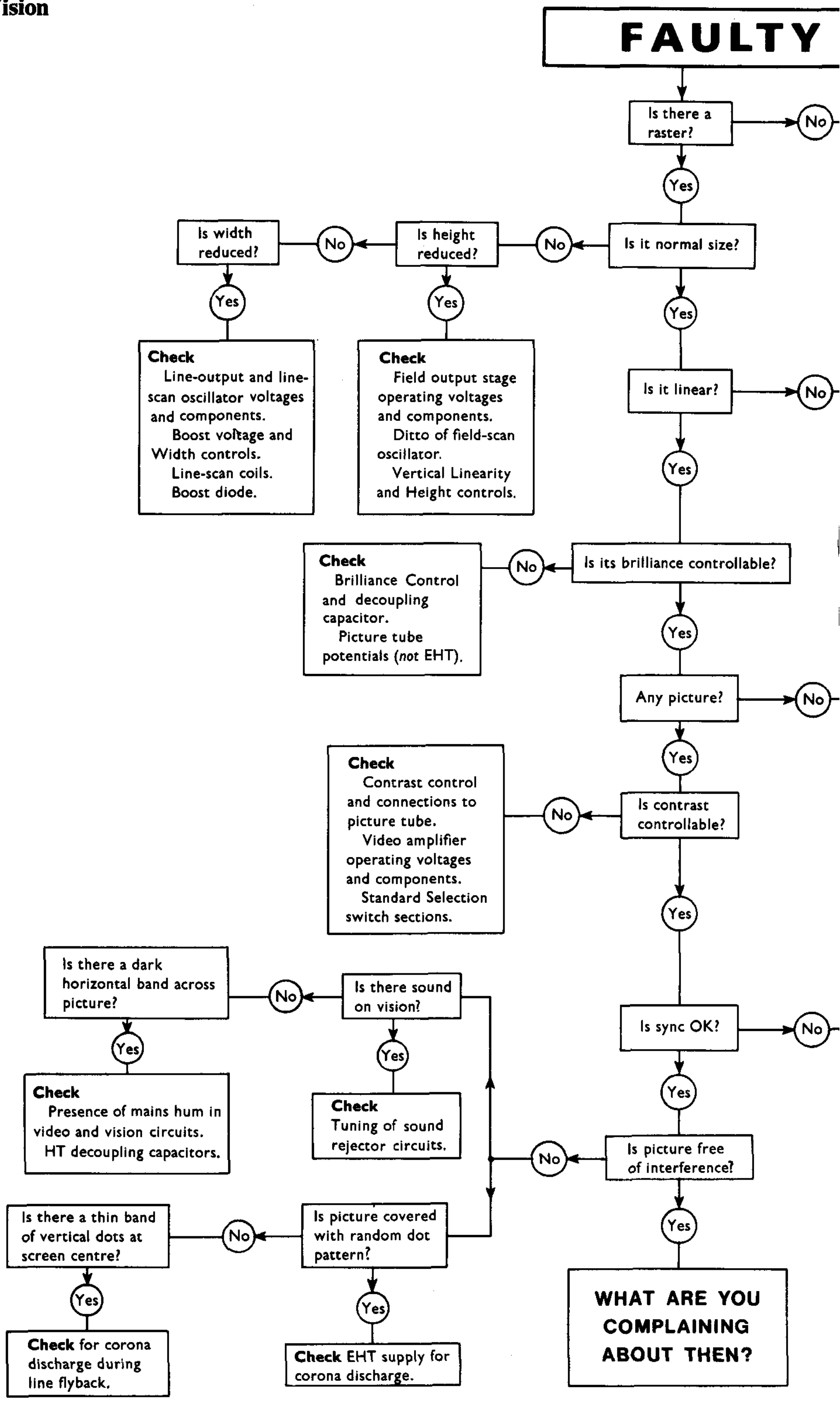
For a lengthy job it can certainly be if there are a large number of valves in the set, and every one of them has to be taken out in turn and checked individually for heater continuity.

A simpler, though potentially more risky, way of doing this is to connect a pair of short insulated wires to a 68-ohm wire-wound resistor rated at about 6 watts, and to connect the other ends of the wires to a pair of prods which are fully insulated apart from their tips. Then touch these prods for a short period across the heater connections of every valve in turn.

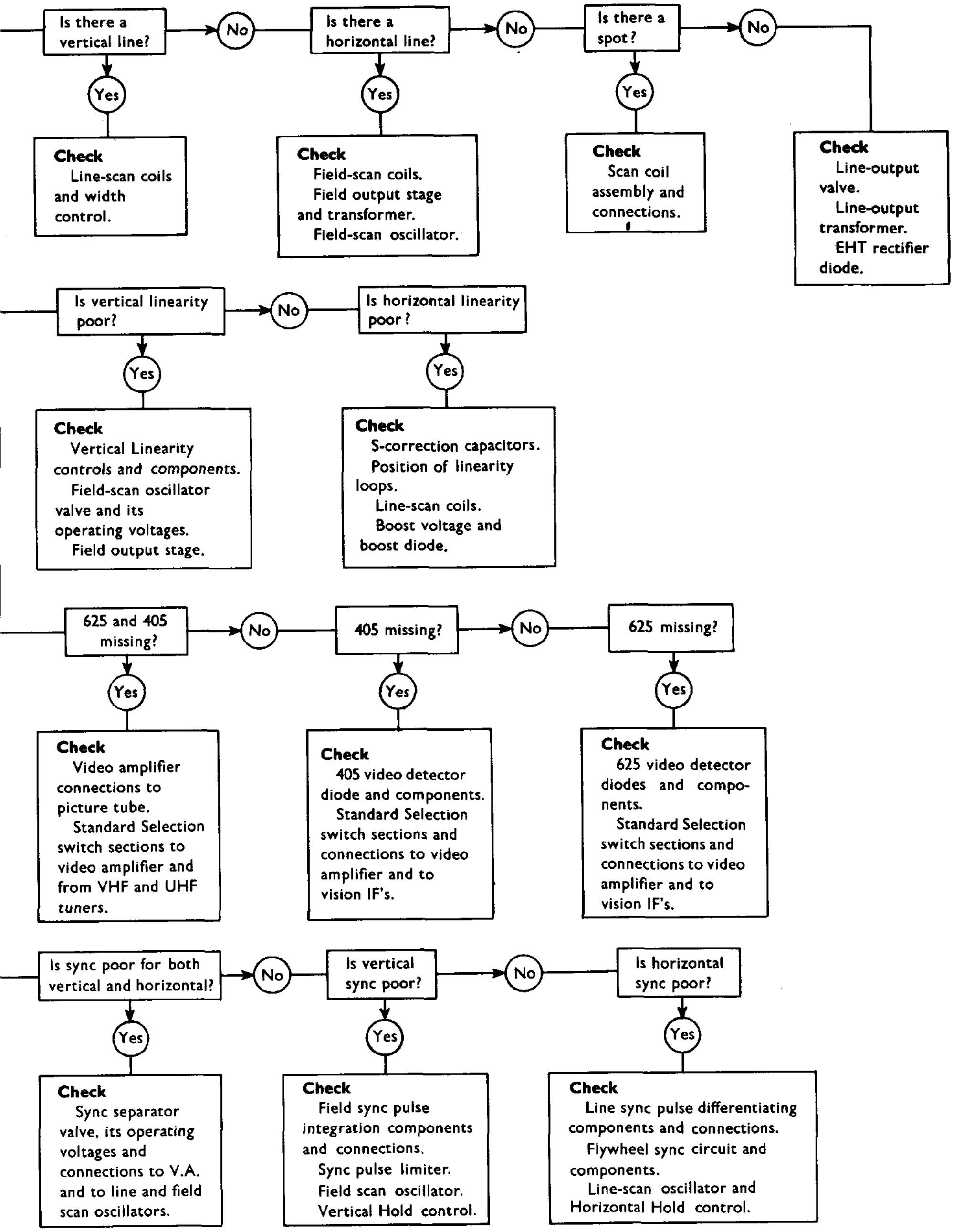
As soon as the valve with a faulty heater is reached, *every other valve heater in the chain* will light up—for the reason that continuity of the whole chain will have been restored by the 68-ohm resistor. The value of this resistor was purposely chosen as being representative of the "hot" resistance of a typical valve heater.

Since this test must be made with the set switched ON, great care must be taken when carrying it out. If you are unsure of your ability to do it safely, substitute for the prods a pair of crocodile clips, and connect them across each valve in turn *with the set switched OFF.* Switch it on only when the connection is securely made, and when you and your hands are well clear of the danger area.

Faulty Vision



VISION



FAULT LOCATION CHART No. 3

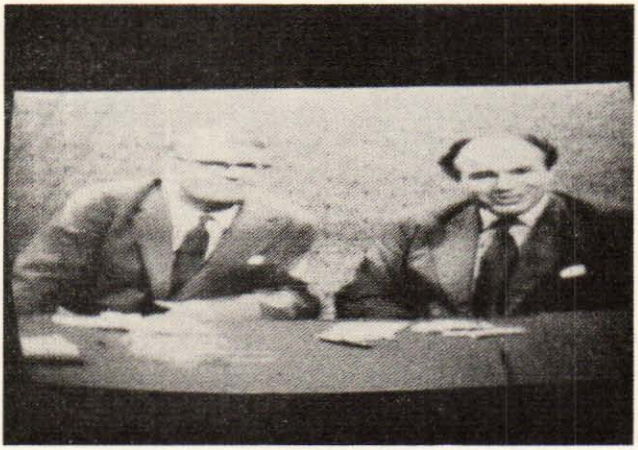
Some Typical Fault Symptoms

The next few pages of this Section describe and illustrate a round dozen fault symptoms which could affect the picture displayed on the screen of any TV receiver. The most probable places in which to look for the cause of the fault symptoms are discussed.

1 Reduced Picture Height

The symptoms are that the picture is reduced to a few centimetres in height, though its width remains normal The vertical linearity of the picture, despite its reduced height, remains normal also and is still controllable by the Height, or Vertical Linearity, control.

REDUCED PICTURE HEIGHT



If the height, small as it is, does remain controllable by the Height control, the fault is due either to incorrect bias voltage to the cathode of the field output valve (though this would admittedly tend to cause some loss of linearity) or, more probably, to an open-circuit in the cathode bias decoupling capacitor. This large-value capacitor (it has typically a capacitance of 50 to 200 μF) is prone to failure of this sort. When it goes open-circuit, there is no decoupling for the cathode bias resistor and a large amount of negative feedback is applied to the field output valve. This severely reduces its overall amplification—whence the loss of height—but also brings about significant improvement in vertical linearity thanks to the power of negative feedback to reduce distortion.

If the height of the picture is *not* controllable by the Vertical Linearity control, the fault is almost certainly to be looked for in the circuitry of the control itself.

2 Line Tearing

The symptoms of this fault are a series of meaningless lines disrupting several areas of the picture. A possible cause is weak signal strength, and it is especially common in fringe areas of reception.

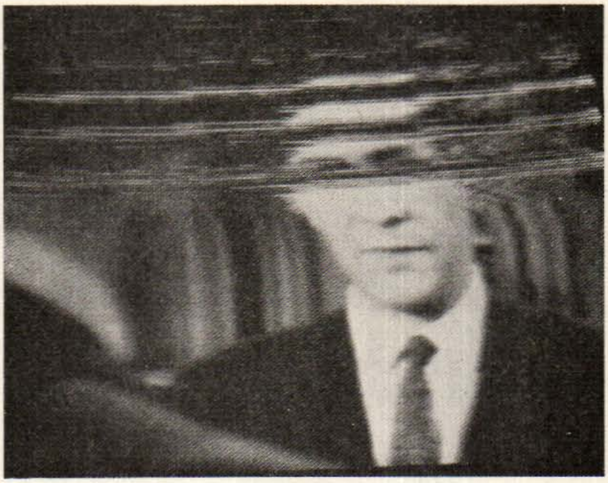
A temporary cure can often be effected by re-setting the Line Hold control; but the setting of this control is very critical, and the cure tends to be short-lived.

Possible seats of the fault itself include damage to the aerial; but more likely ones are the Line Hold control itself or components in the sync separator stage, especially the capacitors coupling the video amplifier to the sync separator or those coupling the line sync pulses to the line oscillator.

Line Tearing (*continued*)

Line tearing is particularly liable to occur in receivers not employing flywheel synchronisation—in which case it is the edges of the picture which take on a ragged appearance.

LINE TEARING

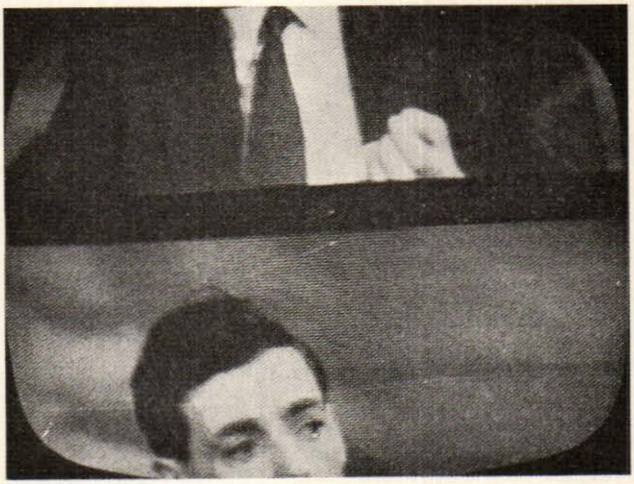


The origin of the fault is generally sharp bursts of noise pulses causing erratic triggering of the line scan generator—which they are often apt to do in areas of weak signal strength.

3 Poor Vertical Hold

In this type of fault, the picture appears to be slipping down from top to bottom of the screen rather as if it were a series of pictures mounted on an unwinding roller-blind.

POOR VERTICAL HOLD



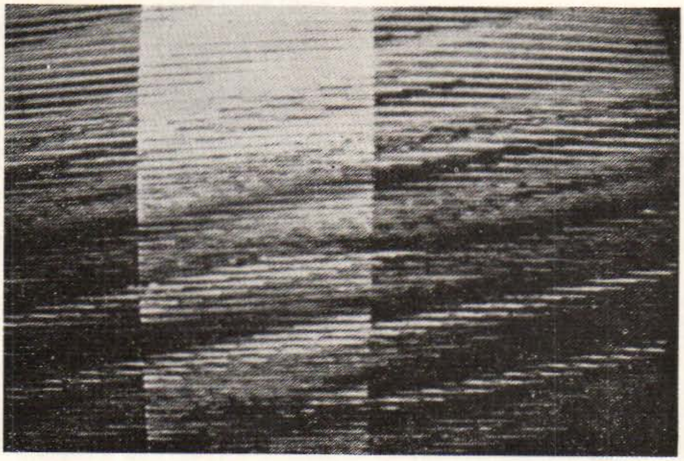
It is sometimes possible to lock the picture by careful adjustment of the Vertical Hold control; but the setting of this control also is usually critical, and here again the cure tends to be short-lived.

The cause of the fault is often a faulty component preventing the field sync pulses from reaching the field scan generator; or it may be trouble in the Vertical Hold control itself, or in an internal preset hold control.

❹ Complete Loss of Synchronisation

The raster is completely unsynchronised in both horizontal and vertical dimensions. The picture, if it can be called one at all, consists of a meaningless pattern of lines and shapes drifting aimlessly up or down the screen from top to bottom.

COMPLETE LOSS OF SYNC



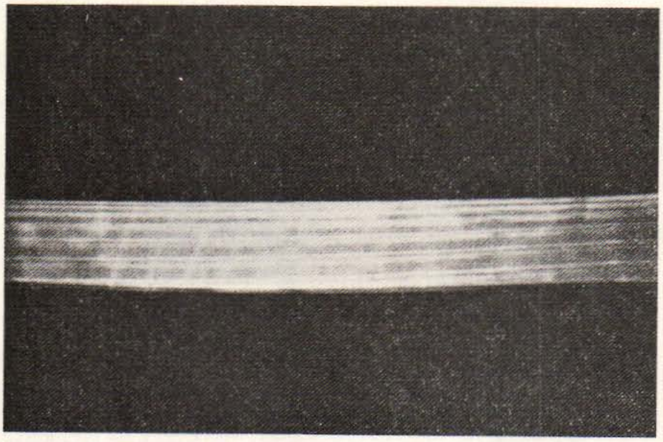
Since the synchronisation of both line and field scans is affected, it is clear that the fault must lie in a section of the receiver which influences the synchronisation of both line and field scan generators. The most likely cause of the trouble is a faulty sync separator valve, or damage to a component connected to one of its electrodes. Alternatively, it could be a fault in the capacitor coupling the sync separator to the video amplifier.

Another possible cause could be something wrong with the VA itself or with one of its associated components. More rare would be misalignment of the vision i.f. stages, causing distortion of the sync pulses before they reach the sync separator stage.

❺ Collapse of Field

The only thing visible on the screen is a narrow band of meaningless lines and patterns. The Vertical Hold is ineffective, and it is impossible to obtain a stable picture.

COLLAPSE OF FIELD



Such symptoms are usually caused by a fault in the field output valve or in one of the components connected to it, or by damage in the field output transformer.

6 **Picture "Wavy" and Laterally Displaced**

With this type of fault, the vertical (field) stability of the picture is quite good but parts of the picture tend to drift off to right or to left of their proper positions. The picture develops a wavy pattern, and needs constant adjustment of the *Line Hold* to keep it steady.

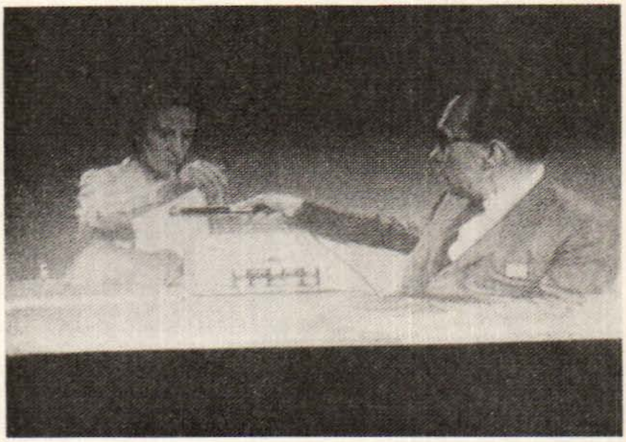
Picture WAVY, with Lateral Displacement

When the horizontal (line) synchronisation is as poor as this, the fault is usually to be found in that part of the receiver circuitry which lies between the sync separator and the line scan generator. The sync separator itself is probably all right because the vertical synchronisation of the picture is not affected. Suspect components are therefore those forming part of the *CR* differentiating stages in the circuit producing the line sync pulses, or any component whose failure could upset the flywheel sync circuit. Faulty operation of the line scan generator itself is another possibility.

7 **Vertical Foldover**

The lower region of the picture appears to be lifted and folded back on to the part of the picture immediately above it. The bottom of the screen is often left blank.

FOLDOVER at Foot of Picture

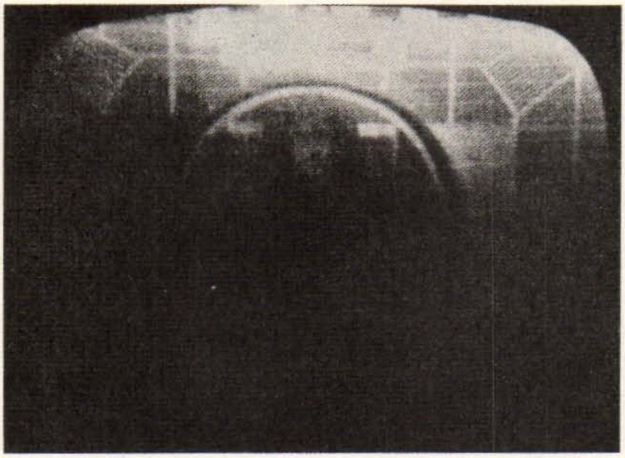


A fault of this kind is usually caused by malfunction of the field scan generator, or of the field output valve. Likely causes of the trouble are leaking coupling capacitors, incorrect valve bias, anode or screen resistors of the wrong value, too low an HT supply, or valves with poor emission from a "poisoned" cathode.

8 Hum Bar on Picture

The symptoms are a thick dark band lying horizontally across a large area of the picture. It is usually accompanied by a low hum from the loudspeaker, deriving from the 50 Hz mains supply; but occasionally the bar appears across the picture with no hum present.

HUM BAR across Picture



When the mains hum is present in the loudspeaker, the trouble is usually only a faulty smoothing capacitor in the HT power supply circuit. Things are more serious when the bar is present but the hum is not. The first thing to examine then is the picture tube, looking in particular for a short-circuit between the cathode and its heater. The remedy could be to connect a separate heater transformer for the picture tube, with the aim of isolating the heater circuit from the rest of the receiver. The only alternative is to replace the picture tube itself.

9 Trapezium Distortion

The symptom is a picture of the correct depth on the left-hand side of the screen narrowing gradually at both top and bottom until it is only some 70% of the correct depth on the right-hand side.

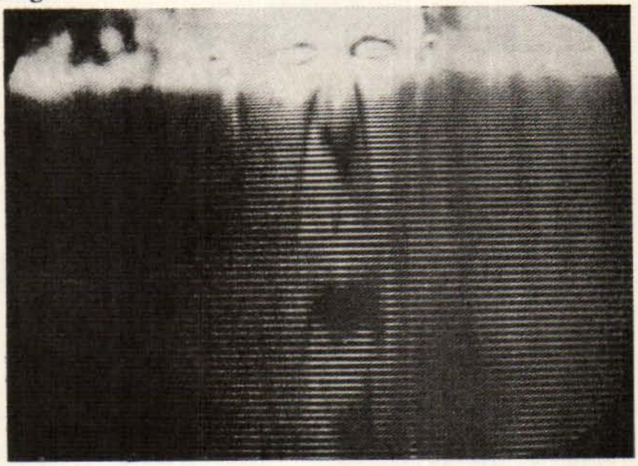
Trapezium Distortion

A fault like this is almost always caused by an internal short-circuit within the field coil assembly, usually between a single pair of adjacent turns on one field coil. The only remedy is to replace the coil assembly—which usually means replacing the line coils as well.

⓾ Severe Vertical Distortion of Picture

The comic picture below of a gentleman with a very bad smell under his nose is an example of sharp vertical non-linearity caused by a fault in either the field scan generator or the field output stage.

Vertical Non-Linearity

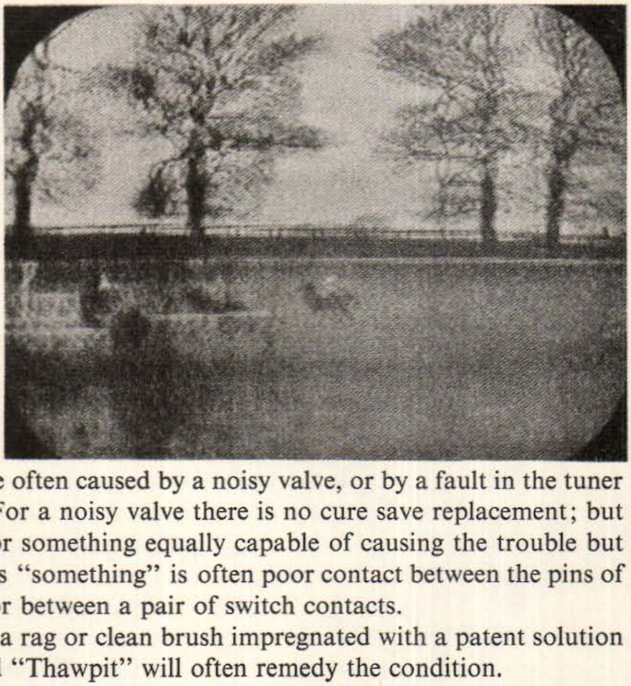


Possible sources of the trouble are: (*a*) faulty valves in either of these stages; (*b*) incorrect bias voltage on one or more of these valves; (*c*) an open-circuit in the vertical linearity control or in one of the components associated with it; (*d*) leaky coupling capacitors; (*e*) too low a voltage on the screen of the field output valve.

⓫ Grainy Picture

A grey, spotty picture like the one below, with very poor overall definition, would be infuriating if you had had a bet on the race about to start!

Picture GRAINY



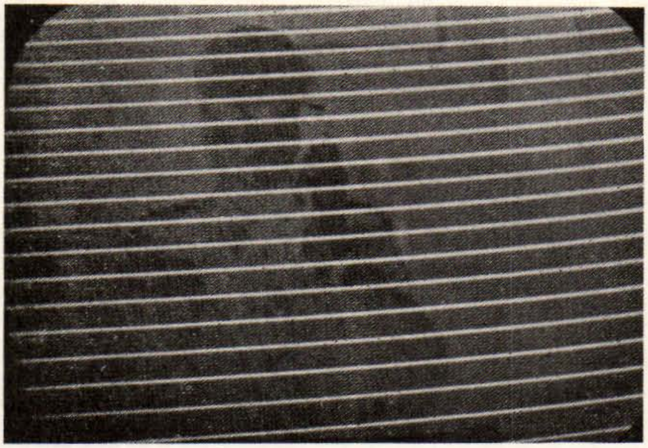
Symptoms such as these are often caused by a noisy valve, or by a fault in the tuner or in the vision i.f. stages. For a noisy valve there is no cure save replacement; but it is worth looking around for something equally capable of causing the trouble but which is easier to cure. This "something" is often poor contact between the pins of a valve and its valveholder, or between a pair of switch contacts.

A thorough cleaning using a rag or clean brush impregnated with a patent solution of carbon tetrachloride called "Thawpit" will often remedy the condition.

12 Negative Picture

A picture like this resembles the negative of a family snapshot plus movement, and plus also a number of prominent white lines running horizontally across the picture.

Picture NEGATIVE



Though it looks at first sight as if a faulty picture tube is the obvious source of the trouble, it is in fact those prominent flyback lines which give the clue to a more probable cause. For they generally indicate that the fault is caused by abnormal working in the video output stage.

Points to check include the operating voltages of the valves in the output stage, the values of the several resistors in the stage, and the continuity of the frequency-compensation inductors. The coupling capacitors in the circuit should also be checked for an open circuit.

Test Equipment—The CRO

Once the fault has been located to a particular section of the receiver, it is usually necessary to carry out a number of follow-up measurements of voltage, current and/or resistance to pin-point the fault to an actual component or connection. This process is considerably assisted if a cathode-ray oscilloscope (CRO), such as that shown, is available for inspecting the various waveforms at different points in the receiver.

The usefulness of a CRO lies in the fact that it can often enable a faulty component to be quickly located by showing up on its screen either the absence of, or the degree of distortion present in, the waveform which ought to be present at a particular point in the equipment circuitry.

It is not easy, for instance, to verify the presence of an open-circuit in a low-value capacitor without resorting either to direct substitution "on spec" or to the use of a rarely-used capacitance-measuring instrument. But the CRO will quickly show that all is not well in that part of the circuit by the abnormality of the waveform it displays on its screen.

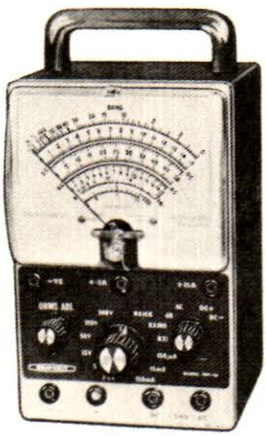
Test Equipment—The CRO (*continued*)

The TV waveforms which can most easily be inspected on a CRO are those of the video signal, the line and field sync pulses both before and after separation, and the demodulated sound (audio) signal.

The selection of a suitable CRO for television fault-finding is, as usual, governed by the conditions which the instrument will be likely to meet. Since you are going to be examining waveforms most of which have very sharp edges (and therefore a high frequency content), the frequency response of the internal "Y" amplifier of your CRO must obviously be wide enough to reproduce these edges without itself introducing distortion in the waveform being inspected. Thus the frequency bandwidth of the internal "Y" amplifier of a suitable CRO should be of the order of 3 MHz or better. Its sensitivity (the sensitivity of a CRO is expressed in millivolts per centimetre) should be 100 mV/cm or better; and it should preferably have a calibrated input-signal attenuator. The timebase sweep rates should extend from about 1 μs/cm to 5 ms/cm, and the triggering facility should be positive and stable.

The Multimeter

Often, however, it will be neither possible nor necessary to use a CRO, and fault-finding procedure will depend on simple measurements of voltage, current or resistance. For this purpose a multi-range testmeter (commonly abbreviated to "multimeter") capable of measuring resistance and a wide range of d.c. voltages and currents is an essential piece of equipment.



The range of voltages which a multimeter suitable for use in a TV receiver should be able to measure would extend from about 0·5 V for measuring such things as grid bias and AGC voltages to about 700 V for the boost voltage and the potential on the first anode. As regards current, the ability to measure from half-a-milliampere to some 300 mA would be adequate.

Typical resistance values which might be encountered range from a few ohms in the scanning coils to several megohms in the grid bias resistors. For this formidable dynamic range, however, a "multi" possessing a measurement range extending from about 1 k to 1 M would be a reasonable compromise.

The internal resistance (and hence sensitivity) of the multimeter should be as high as possible so that its presence does not appreciably affect the operation of the circuit when voltages developed across high-value resistors such as the anode and screen load resistors are being measured. The sensitivity of a testmeter is expressed in ohms per volt, and a good-quality multimeter should have a sensitivity of at least 20,000 Ω/V. Certainly anything less than 10,000 Ω/V would be of little value.

Note that it is very seldom necessary to measure *a.c. voltage* when fault-finding in a TV receiver. There is usually only one source of a.c. voltage, the mains supply; and the presence or absence of this is easily detected with the aid of an electric light bulb and two short pieces of wire.

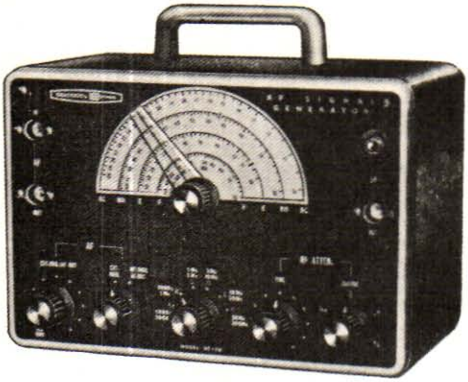
The AVOmeter

If you are a prosperous sort of chap with a growing repair business, a desirable possession is a type of multimeter called the "AVO Model 8". This reliable and rugged instrument, with 20,000 Ω/V sensitivity and a large number of ranges, is highly regarded in "the trade"; but the more humble operator or repairman will find that some of the many 20,000 Ω/V multimeters advertised in the popular technical magazines offer good value for an outlay of a few pounds.

One final word of warning to be borne in mind when you are using a multimeter of any kind. *Always check that you have it set to the correct range before you make any sort of measurement with it.* You would be surprised how many "pro's" with long years of experience behind them still forget this simple rule—and how many rather expensive testmeters are ruined in consequence.

The Signal Generator

A piece of equipment of essential value to the professional service engineer is an r.f. signal generator of the type pictured below. With such an instrument he can improvise a steady signal at the aerial socket of any TV receiver he is testing, setting it to the frequency of any particular channel or to any sound or vision carrier frequency within that channel. This makes him independent of all fixed-time test transmissions and enables him to work on a receiver at any time which suits him or his client.



A typical TV
SIGNAL GENERATOR

The principal use to which a professional repairman puts a TV signal generator is to help him in the re-alignment of the r.f. stages in the tuner. Alternatively, he can reset the instrument to the much lower i.f. frequencies and use it to help him align the sound or vision i.f. stages. In addition, most signal generators provide means for introducing a fixed amount of amplitude modulation into the signal they generate, so that an "audio output" appears at the loudspeaker during alignment. This can be used either as an aid to correcting alignment or as a means of checking the efficiency of the demodulation process and all the subsequent audio circuits.

The do-it-yourself fault-finder has much less need of a signal generator; for the need to re-align an individual TV receiver comes but rarely, and the process of alignment is in any case not the sort of task which should be lightly undertaken—certainly not without full alignment instructions from the manufacturer of the receiver.

As you would expect, the signal generators suitable for TV servicing which possess the most comprehensive range are also the most expensive. Such generators can produce signals over the entire frequency spectrum from Band 1 to Band 5. Less expensive models cover the frequencies in Bands 1 to 3; while cheaper ones still are limited to the sound and vision i.f. frequencies only.

§26: TRENDS IN TV RECEIVER DESIGN

The reasons why this Series on *Basic Television* has been almost wholly explained in terms of the thermionic valve, despite the progressive replacement of the valve in many modern receivers by semiconductor devices of various kinds, have been briefly mentioned in the Preface. The second of the reasons there given was basically instructional convenience and efficiency, and no more will be said of it here; but the first reason, which postulated that the valve will continue to find significant use in TV receivers for some years to come, calls for a brief outline of some of the technical and commercial considerations which affect manufacturing and marketing decisions by TV manufacturers in Britain in the latter half of the year 1971.

Among the most relevant of these considerations are the following:

1. **Though the semiconductor device (commonly, though not always accurately, spoken of generically as "the transistor") has many advantages over the valve—principally in its small size, low power consumption and greater robustness, but increasingly also in lower manufacturing cost—it can seldom be used in straight substitution for a valve without considerable re-design of associated components.**

2. **Re-design of an existing chassis, and tooling-up to mass-produce it thereafter, is an expensive business—not lightly to be undertaken save at relatively long intervals during a period of swift technological change like the present.**

3. **Though the 405-line system in Great Britain will certainly be replaced sometime, nobody yet knows when that "sometime" will be. As long as VHF transmissions on 405 lines continue, receivers will be needed to pick them up. But it is unrealistic to expect such receivers, with their limited life expectation however well they are made, to be continually re-designed to keep up with technical advances.**

For these reasons, there are grounds for thinking that the thermionic valve—efficient, well tried-and-tested in a wide range of operating conditions, and not yet priced out of the market for many TV requirements—will remain in significant use for a considerable time after it has become technologically obsolescent.

It is not a waste of time learning how the many valves of various kinds used in the British Dual-Standard Receiver do their job, for they will probably still be there for some years to come.

The Semiconductor in TV Receiver Design

The first valve-type component to be replaced by a semiconductor equivalent was the diode, for the S/C diode is much smaller and more reliable, and can be substituted for the valve diode without creating any considerable difficulty in the design of associated circuitry. The change took place many years ago, as soon as the semiconductor diode became competitive in price.

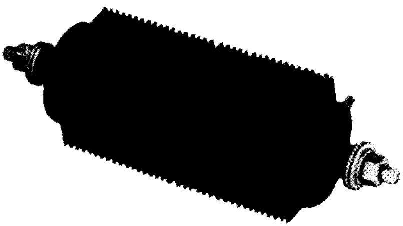
Stages of the receiver into which the S/C diode was introduced included those handling signal demodulation, AGC and the limitation of noise. In these applications diodes of suitable rating were designed which occupied only a fraction of the space demanded by their valve-type counterparts and which consumed virtually no power (because they require no heater supply). They had thus the further advantage of not contributing to the heat-dissipation problem in the receiver.

The Semiconductor in TV Receiver Design (*continued*)

Other important stages of the receiver into which the S/C diode was early introduced were those handling the rectification of the alternating mains current, and generation of the HT(+) supply. In the early receivers, large metal rectifiers of the copper-oxide or selenium type such as those illustrated in *Basic Electricity*, page 3.21, had been exclusively used. They were heavy and large—often more than 100 mm in length and 50 mm in effective diameter—but reliable and robust under conditions of severe usage.

These rectifiers were later superseded in many models by smaller and lighter valve-type diodes, two of which were often connected in parallel to provide the large current flows required by receivers containing many valves. These valve-type diodes, of course, ran at high temperatures, so contributing to the overall heat generated within the cabinet, and they suffered from the additional disadvantage of being much less reliable than the metal rectifiers.

Nowadays, however, this sort of job is almost always done by a single semiconductor diode less than half the size of a thimble. It is not only smaller, lighter and cheaper than the heavy rectifier and the valve diode, but by reason of its much lower forward voltage drop is far more efficient electrically than either of them.



An old-style METAL RECTIFIER

A modern SEMICONDUCTOR DIODE

The Transistor in TV Receiver Design

The replacement of the principal triode and pentode, etc. operating valves in the TV receiver has been a much slower process, and even now is far from complete. Granted that some of the latest colour receivers contain no valves at all, many of the latest monochrome receivers, even those of single-standard 625-line type, are still no more than 50% transistorised.

The reasons for this are those of commercial logic. Look inside several of the many different makes of receivers which are marketed today under various brand names, and you will see that they differ principally in external appearance. Inside, you will find that no more than three or four different types of chassis are used, all designed and assembled by one or other of the small number of large component manufacturers who make for others but are not directly concerned with selling a finished product. When a well-designed chassis is selling well and when (as is often the case) it uses valves produced by the chassis manufacturer himself at a cost often significantly lower to him than would be that of a transistor counterpart, the incentive to produce a new design based entirely on the use of transistors and other semiconductor devices is limited.

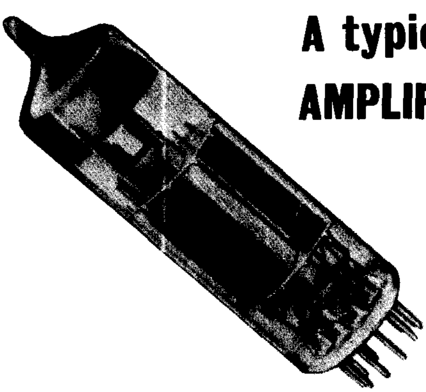
The Transistor in TV Receiver Design (*continued*)

This is especially true of receivers capable of receiving programmes transmitted at VHF on the 405-line system. It is known that this system will one day be phased out completely, but the decision when this will actually happen is a political one—and not by any means an easy one either. There exist in Britain today many tens of thousands of TV receivers capable of receiving 405-line programmes *only*. Their owners are not unhappy with the programme variety they are getting for their money at present and will thank no one for a decision whose effect (as they may well see it) is to make their present receiver useless in the interests of a further advance in technical progress whose benefits they do not want at the price. Since a high proportion of these folk are likely, in the nature of things, to belong to the less affluent sections of the electorate (old-age pensioners and the like), the difficulties of the man who must one day take the fateful decision are obvious.

The only sets currently being manufactured which are capable of receiving programmes broadcast at VHF on the 405-line system are Dual-Standard Receivers of the type described in this Series. For the reasons given above, it seems probable that this Receiver may have a good long life still ahead of it, and that valves will continue to be used in its circuitry for as long as it continues to be made.

Two main difficulties face manufacturers wishing to replace, *e.g.*, an amplifying valve with a transistor equivalent. The first is that it is not so simple a job as it was with the diode. The operating voltages are completely different, and so are the amplifying parameters and the input and output impedances. A good deal of re-design is thus necessary in any case—and since a transistor amplifier is so small by comparison with the valve it replaces, the second difficulty is to know where to stop. Why not take advantage of very small component size to reduce the overall dimensions of the cabinet itself?—and at once you are faced with the need for a new chassis, new cabinet styling, heavy tooling-up expenses and all the other manufacturing and promotional costs of launching a completely new model.

In the illustration below, a typical TV amplifier valve shown (*both actual size*) alongside a transistor device capable of replacing it entirely demonstrates the extent of the opportunity, and of the challenge, presented.



A typical AMPLIFIER PENTODE

and its TRANSISTOR EQUIVALENT

The Transistor in TV Receiver Design (*continued*)

Historically, the first section of the receiver to be transistorised was the UHF Tuner stage—principally because it was a new item in the overall circuit which had not been needed at all before the coming of UHF transmission. There were therefore no reasons of commercial or other logic why it should not be designed around the most efficient and up-to-date components from the start.

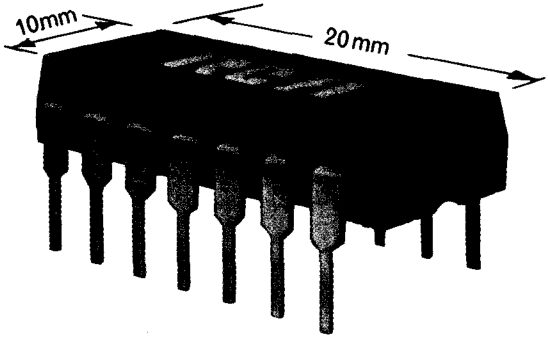
Later came the transistorisation of separate, discrete sections of the receiver circuitry such as the sound and vision IF stages; but the more complex sections such as the line and field output stages, together with the ones which have to handle high voltages like the EHT power supply, still largely depend on the use of valves. Indeed, it is only quite recently that transistors capable of performing *all* the functions of the valve in a TV receiver have become available at an economic price.

Looking to the Future

A significant aspect of recent design philosophy is the concept of *modular construction*, in which entire stages or parts of stages in the TV receiver are manufactured as a complete unit which can be replaced by plugging in another unit of the right kind if anything should go wrong with the circuitry of the first.

Plug-in units of this kind can be wired in the normal way, but more often they are designed to take advantage of the greater neatness and compactness afforded by another development of recent years called *printed circuit wiring*. In PCW, the wiring of the components making up whole sections of the circuitry of a TV receiver is formed by etching away all unwanted areas of the thin metal backing of the insulated board on which the components are mounted. A completed *circuit card*, as it is called, is thus a maze-like arrangement of flat metal strips mounted side by side—each strip no more than a fraction of a millimetre thick and each having a different wiring pattern etched into its surface. Complete circuit cards are then plugged into appropriate sockets on the chassis, with the result that the initial assembly, testing and alignment are greatly simplified. Later, the all-important servicing becomes merely a matter of tracing the fault to a particular card and replacing it with a new one. The old card is then sent for repair by an experienced specialist in the workshop.

More advanced circuit designs still are making use of *integrated circuits* for some sections of the receiver. These are devices, often no larger than a postage stamp, which carry in the semiconductor-type material of which they are made whole circuits otherwise requiring scores of transistors, diodes, resistors and capacitors. A frequency-modulated sound IF circuit, for example, complete with ratio detector, can be bought today in integrated circuit form contained in a "package" like the one shown *more than twice actual size* in the illustration below.



A COMPLETE FREQUENCY-MODULATED SOUND IF CIRCUIT IN ***Integrated Circuit*** FORM

Looking to the Future (*continued*)

This is undoubtedly the direction in which design is moving; and eventually all TV receivers will be of the integrated-circuit type. Before this comes about, however, the picture tube of today, with its electron-beam scanning and enormous HT voltage requirement, will need to be replaced by a matrix of light-emitting diodes scanned by a system of electron switching. TV receivers operating on this advanced technique should become commercially available before the 1970's are out.

INDEX TO PART 3

Aluminizing 3.81
Automatic Gain Control (AGC) 3.93 *et seq.*
Auto-Transformer 3.57
AVOmeter 3.132

Black Spotter 3.90 *et seq.*
Blocking (of Mean-Level AGC) 3.102 *et seq.*
Blocking Oscillator 3.18 *et seq.*
Boost Diode 3.55 *et seq.*
Brightness Control 3.16

Cathode Ray Oscilloscope (CRO) 3.130 *et seq.*
Circuit Cards 3.136
Clipping Level (of Limiter) 3.14
Coincidence Detector 3.27 *et seq.*
Collapse of Picture Field 3.126
Colour Coding (of Wiring) 3.112
Contrast Control 3.99 *et seq.*
Corner Cutting 3.76
Corona Discharge 3.63
Cross-Talk 3.46

Deflection of Scanning Beam 3.72 *et seq.*
Delayed AGC 3.97
Direct-View Picture Tube 3.82
Double-Delayed AGC 3.98

Efficiency Diode 3.53
EHT Smoothing 3.82
— Voltage Generation 3.59 *et seq.*
Electron Gun Assembly 3.67 *et seq.*
Equalizing Pulses 3.13

Fault-Finding 3.117 *et seq.*
Fault Location Charts C.118 *et seq.*
Faulty Sound 3.120
Field Hold 3.19
— Output Stage 3.17, 3.42 *et seq.*
— Scan Generator 3.16, 3.18 *et seq.*
— Scanning Coils 3.16, 3.40 *et seq.*, 3.72 *et seq.*
— Sync Pulse Limiter 3.14
— — — Separation 3.8 *et seq.*
Final Anode 3.67 *et seq.*
Flywheel Synchronization 3.24 *et seq.*

Focusing (of Electron Beam) 3.69 *et seq.*
—, Electromagnetic 3.71
—, Electrostatic 3.69 *et seq.*
Frequency Comparison 3.26 *et seq.*

Gated AGC 3.104 *et seq.*
Ghosts (TV) 3.84
Grainy Picture 3.129

HT Supply 3.113
Hum Bar, on Picture 3.128

Integrated Circuits 3.136
Ion Burn 3.80 *et seq.*
Ion-Trap Magnet 3.80

Limiter (of Field Sync Pulse) 3.14
Line Hold 3.19
— Output Stage 3.17, 3.48 *et seq.*
— Pairing 3.12
— Scan Generator 3.17, 3.18 *et seq.*
— Scanning Coils 3.16, 3.49 *et seq.*
— Sync Pulse 3.2
— — — Separation 3.6 *et seq.*
— Tearing 3.24, 3.124 *et seq.*
Linearity Correction 3.79
Loss of Sync 3.126
LT Supply 3.114 *et seq.*

Magnetostrictive Effect 3.58
Mean-Level AGC 3.96 *et seq.*
Modular Construction 3.136
Multimeter 3.131
Multivibrator 3.20 *et seq.*

Negative Picture 3.130
Noise-Gating (of Sync Pulse Separator) 3.92

Pautagrid 3.92
Phase Detector 3.32 *et seq.*
— Discriminator 3.34
— Misalignment 3.37

Picture Centering 3.78
— Correction Magnets 3.77
— Tube 3.66 *et seq.*
Power Supplies 3.112 *et seq.*
Pull-in Time 3.36

RC Damping 3.52
Reduced Picture Height 3.124

S-Correction 3.41 *et seq.*
Signal Generator 3.132
Sync Pulses 3.2
— Separator 3.3 *et seq.*

Test Card "F" 3.83 *et seq.*
— Equipment 3.130 *et seq.*
Thermistor 3.115
Third Harmonic Tuning 3.60 *et seq.*
Transformer Whistle 3.58
Trapezium Distortion 3.128

Valve Heaters 3.114 *et seq.*
Vertical Hold, Correction of 3.125
— Foldover 3.127
— Linearity Control 3.44 *et seq.*
— Non-Linearity 3.129
Vision Interference Limiters 3.87 *et seq.*

Wavy Picture 3.127
Width Control of Picture 3.58

Zero Initial Slope (of Waveform) 3.43

CUMULATIVE INDEX to PARTS 1–3

Acceptance Angle 2.44
— Bandwidth 2.25, 2.39 *et seq.*
Aerials, Receiving 2.4, 2.17 *et seq.*
— Transmitting 1.114 *et seq.*, 1.126
Aeroplane Flutter 2.139
Afterglow 1.29
AGC Blocking 2.102
Aluminizing 3.81
Aspect Ratio 1.36, 1.134
Audio Amplifier 2.114
Automatic Gain Control (AGC) 2.9, 3.93 *et seq.*
Auto-Transformer 3.57
AVOmeter 3.132

Back Porch 1.70
— Projection 1.96
Band, Frequency 1.125
Bandpass Filter 2.51, 2.97
Bandwidth, Signal 1.131 *et seq.*
Bat-wing Aerial 2.40
Beat-frequency Interference (in VA) 2.132
Bias levels in VA 2.127 *et seq.*
Black-Level Reference Signal 1.48
Black Spotter 3.90 *et seq.*
Blanking Pulse 1.45, 1.57
— Waveform 1.69, 1.72
Blocking (of Mean-Level AGC) 3.102 *et seq.*
Blocking Oscillator 3.18 *et seq.*
Boost Diode 3.55 *et seq.*
Bottom Capacitance Coupling 2.79
Brightness Control 3.16
Bright-up 1.31
Brilliance Control 2.138
Burn-In, Image 1.57
Caesium 1.12, 1.38, 1.42, 1.52
Camera Chain 1.89
— Control Unit 1.92
— Tube 1.29, 1.37
Carrier Modulation 1.101
— Wave 1.100
Cascode Amplifier 2.61 *et seq.*
Cathode Ray Oscilloscope (CRO) 3.130 *et seq.*
Central Apparatus Room 1.85
— Control Room 1.82, 1.85
Channel, Frequency 1.125
— Selection (in VHF Tuner) 2.66 *et seq.*
Circuit Cards 3.136
Clamping Pulses 2.141
Clipping Level (of Limiter) 3.14
Close-up 1.95
Coincidence Detector 3.27 *et seq.*
Collapse of Picture Field 3.126
Colour Coding (of Wiring) 3.112
Colour (Nature of) 1.8
Conical Dipole Aerial 2.40
Contrast Control 2.133 *et seq.*, 3.99 *et seq.*
— — Knob 2.9
Corner Cutting 3.76
— Reflectors 2.38
Corona Discharge 3.63
Critical Coupling (of tuned circuits) 2.79
Cross-Modulation 2.101
Cross-Talk 3.46
Cutting 1.93

Damping 2.96

D.C. Clamping 2.141
— Component of Picture Signal 2.139
— Level 1.48
— Restoration (in some types of VA) 2.131, 2.141
Decelerator Grid 1.55
De-emphasis Filter 2.114
Definition 1.16
Deflection of Scanning Beam 3.72 *et seq.*
Defocusing 1.94
Delayed AGC 3.97
Delta Matching (of feeder cable to aerial) 2.35, 2.47
Diplexer 2.49 *et seq.*
Dipole Aerials 2.19 *et seq.*
— Length 2.23 *et seq.*
Directivity 1.120
Directors 1.121, 2.28 *et seq.*
Direct-View Picture Tube 3.82
Dissolve 1.94
Double-Delayed AGC 3.98
Double Yagi with Skeleton Slot 2.35
Dynode 1.39

Efficiency Diode 3.53
EHT Smoothing 3.82
— Voltage Generation 3.59 *et seq.*
Electron Gun Assembly 1.41, 3.67 *et seq.*
— Multiplier 1.39, 1.56
End-fed Dipole 2.48
Equalizing Pulses 1.78, 3.13
Eye, Human 1.17

Fade-in, fade-out 1.93
False Perspective 1.97
Fault-Finding 3.117 *et seq.*
Fault Location Charts 3.118 *et seq.*
Faulty Sound 3.120
Feeders, Aerial 1.113, 2.46 *et seq.*
Field 1.32
— Flyback Path 1.72
— Frequency 1.32
— Hold 3.19
— Output Stage 3.17, 3.42 *et seq.*
— Scan Generator 3.16, 3.18 *et seq.*
— Scanning Coils 3.16, 3.40 *et seq.*, 3.72 *et seq.*
— Strength 1.222 *et seq.*
— Sync Pulse 1.72 *et seq.*
— — — Limiter 3.14
— — — Separation 3.8 *et seq.*
Final Anode 1.41, 3.67 *et seq.*
— Transmission Picture 1.87
Flicker 1.26
Flutter, Aerial 2.27
— Aeroplane 2.139
Flyback Period 1.30
— Time 1.69, 1.72
Flywheel Synchronisation 3.24 *et seq.*
Focus Coil 1.52
Focusing (of Electron Beam) 3.69 *et seq.*
— Electromagnetic 3.71
— Electrostatic 3.69 *et seq.*
Folded Dipole 2.30
— Slot Aerial 2.34
Forward Gain (of aerial array) 2.28
Frame 1.32
— Grid Valves 2.64 *et seq.*
Frequency Changers (VHF) 2.68 *et seq.*
— — (UHF) 2.78 *et seq.*
— Comparison 3.26 *et seq.*
— Compensation (in VA) 2.124
— Content (of Video Signal) 1.132 *et seq.*
— Deviation 1.104
— Discriminator 2.104
— Multiplier Circuit 1.100
— Response, of Aerial 2.25 *et seq.*
— — in IF Amplifier 2.92 *et seq.*
— — in Tuner 2.80 *et seq.*
— — in Video Detector 2.118 *et seq.*
Fringe Area 1.123
Front Porch 1.70
Front-to-Back Ratio 2.27
Full-Wave Dipole Aerial 2.20
Fundamental Frequency 1.133

Gated AGC 3.104 *et seq.*
Ghosts (TV) 2.33, 2.42 *et seq.*, 3.84
Grainy Picture 3.129
Grid Modulation (in VA) 2.123
Grounded-Cathode Triode 2.61
Grounded-Grid Triode 2.61

H-Aerial 2.26
HT Supply 3.113
Half-Line Pulses 1.73
Half-tone Photo-engraving 1.15
Half-Wave Dipole Aerials 1.114 *et seq.*, 2.19 *et seq.*, 2.22 *et seq.*
Heat (Nature of) 1.8
High-level Contrast Control (in VA) 2.133
Home-made Aerials 2.52 *et seq.*
Hum Bar, on Picture 3.128

IF Amplifier 2.6, 2.83 *et seq.*
"IF Amplifier A" 2.83, 2.89 *et seq.*, 2.98 *et seq.*
"IF Amplifier B" 2.83, 2.102 *et seq.*
Iconoscope Camera 1.40 *et seq.*
Image Accelerator Grid 1.52
— Orthicon Camera 1.49 *et seq.*
— Sticking 1.57
Incremental Tuning 2.67
Inlay 1.97
Integrated Circuits 3.136
Intercarrier Buzz 2.104
— Signal 2.8, 2.102 *et seq.*
Interference Limiter (at VHF) 2.113
Interlaced Scanning 1.32 *et seq.*
Ion Burn 3.80 *et seq.*
Ion Trap Magnet 3.80

Keying Pulses 2.141

LT Supply 3.114 *et seq.*
Lecher Line 1.108
Lens Turret 1.58
Light (How Converted into Signal) 1.12
— (How Produced) 1.9 *et seq.*
— (Nature of) 1.7
Lighting Supervisor 1.88
Limiter (of Field Sync Pulse) 3.14
Line Hold 3.19
— Output Stage 3.17, 3.48 *et seq.*
— Pairing 3.12
— Scan Generator 3.17, 3.18 *et seq.*
— — Period 1.36
— Scanning Coils 3.16, 3.49 *et seq.*
— — Frequency 1.35
— Sync Pulse 1.69 *et seq.*, 3.2
— — — Separation 3.6 *et seq.*
— Tearing 3.24, 3.124 *et seq.*
Line-of-Sight Transmission 1.121
Linearity Correction 3.79
Loss of Sync 3.126
Loudspeaker 2.115
Low-level Contrast Control (in VA) 2.133

Magnetostrictive Effect 3.58
Master Sync Pulse Generator 1.90
Maximum Picture Signal Frequency 1.133
Mean-Level AGC 3.96 *et seq.*
Microphone 1.6
Miller Effect 2.60
Mixer 2.5
Modular Construction 3.136
Modulating the Picture Tube 2.137
Monitors 1.87
Montage Effects 1.96 *et seq.*
Mosaic 1.37, 1.42
Multi-Element Aerial Arrays 2.29 *et seq.*
Multimeter 3.131
Multivibrator 3.20 *et seq.*
Mutual Conductance (G_m) 2.65

Negative Demodulation 2.117
— Picture 3.130
Neutralising Capacitor 2.63
Nipkow Disk 1.27
Noise-Gating (of Sync Pulse Separator) 3.92

Operating Frequencies (of British TV Transmitters) 1.125
Optical Horizon 1.121
— Window 1.41, 1.60
Over-coupled Tuned Circuits 2.97
Overlay 1.97
Overshoot 2.126

Panning 1.94
Partial D.C. Coupling 2.140
Peaking Coils 2.63, 2.125
Pedestal 1.76
Pentagrid 3.92
Persistence of Vision 1.18
Persuader Grid 1.56
Phase Detector 3.32 *et seq.*
— Discriminator 3.34
— Misalignment 3.37
Photo-cathode 1.13, 1.37, 1.52
Photocell 1.13
Photo-conductive Lag 1.63
Photo-conductivity 1.14, 1.61 *et seq.*
Photo-electricity 1.12
Photo-multiplier 1.39
Photosensitivity 1.12
Picture 1.32
— Centering 3.78
— Correction Magnets 3.77
— Elements 1.16
— Frequency 1.32
— Signal 1.44, 1.64
— Sync Ratio 1.76
— Tube 1.29, 3.66 *et seq.*
Polar Diagram 1.120
Polarisation (of transmitted signals) 1.118, 2.31
Positive Demodulation 2.117
Post-Sync Field Blanking 1.75
Power Gain of Aerials 2.27
— Supplies 2.13, 3.112 *et seq.*
Presentation Suite 1.85
Producer 1.87
Production Control Room 1.87
— Studio 1.85
Pull-in Time 3.36

RC Damping 3.52
R.F. Amplifier Stage of Tuner 2.5, 2.60
Radiation Acceptance Pattern 2.26
Raster, Scanning 1.30
Ratio Detector 2.114
Reactance Modulator 1.104
Reduced Picture Height 3.124
Reflectors 1.121, 2.26, 2.38
Rejector Circuits 2.84 *et seq.*
Resolution 1.16, 1.46, 1.63
Resolving Power 1.16
Resonant Lines 2.72 *et seq.*
Retrace Time 1.69
Ringing 2.126

S-Correction 3.41 *et seq.*
Scan 1.29
Scanning 1.29 *et seq.*
— Frequencies 1.35
— Raster 1.30
Screening (in UHF Tuner) 2.74
Secondary Electrons 1.38
— Emission 1.38
— — Ratio 1.38
Selenium 1.14
Sensitivity (of Iconoscope) 1.46
Sequential Scanning 1.24
Service Area 1.121 *et seq.*
Shading Signals 1.48
Shaping of Frequency Response Curves 2.96 *et seq.*
Sideband Filter 1.109
Sidebands 1.131

Signal Bandwidth 1.131
— Generator 3.132
— Load Resistor 1.45
— Plate 1.42, 1.60
— Power Distribution 2.92 *et seq.*
— Routing 1.82
— Strength Meter 2.41
Signal-to-Noise Ratio 2.44
Silhouette Pulse 1.97
Skeleton Slot Aerials 2.35
Skin Effect 2.74
Skip Distance 1.123
Slot Aerials 2.31 *et seq.*
Slotted Cylinder Transmitting Aerial 2.36
Sound Signal 1.5, 2.110 *et seq.*
— Supervisor 1.88
— Transmitter 1.102 *et seq.*
Sound-on Vision 2.89
Spectral Colours 1.8
Spectrum of Visible Light 1.8
Spill Light 1.96
Stacked Aerial Arrays 2.45
Studio, Television 1.81 *et seq.*
— Floor 1.86
— Manager 1.86
Switching Centre 1.82
Sync Pulses 1.68, 2.10 *et seq.*, 3.2
— Separator 3.3 *et seq.*

T.Matching (of feeder cable to aerial) 2.47
Talk-back Apparatus 1.92
Target 1.29, 1.37, 1.54, 1.60
— Mesh 1.52, 1.60
Telecine Machine 1.84
Test Card "F" 3.83 *et seq.*
— Equipment 3.130 *et seq.*
Thermistor 3.115
Third Harmonic Tuning 3.60 *et seq.*
Tilt 1.95
— Angle 1.128
Timebase 1.29
Tonal Content (of Scene) 1.15
Trace 1.29
Transformer Whistle 3.58
Transmitter, Vision 1.100 *et seq.*
Transmitting Aerial 1.114 *et seq.*, 1.126
Trapezium Distortion 3.128
Traps 2.84 *et seq.*
Triplexer 2.51
Tuner Stage of Receiver 2.5, 2.59 *et seq.*
Turret Tuning 2.66

UHF Aerials 2.37 *et seq.*
— Triode (in RF Amplifier) 2.76 *et seq.*
— Tuner 2.71 *et seq.*
Undercoupled Tuned Circuits 2.97
Unipole 2.48

VHF Tuner 2.60 *et seq.*
Valve Heaters 3.114 *et seq.*
Vertical Hold, Correction of 3.125
— Foldover 3.127
— Linearity Control 3.44 *et seq.*
— Non-Linearity 3.129
Vestigial Sideband Transmission 1.109
Video Amplifier 2.8, 2.122 *et seq.*
— Detector 2.18, 2.116 *et seq.*
— Effects 1.98
— Signal 1.68
Video-Tape Machine 1.84
Vidicon Camera 1.60 *et seq.*
Viewfinder 1.58, 1.60
Vision Interference Limiters 3.87 *et seq.*
— Mixer 1.87
— Signal 1.5
— Supervisor 1.88
— Transmitter 1.100
Vision-on-Sound 2.89

Wall Anode 1.55, 1.60
Waveband of Visible Light 1.7
Wavy Picture 3.127
Width Control of Picture 3.58
Wipe 1.97
Wire Mesh Reflectors 2.39

Yagi Aerials 2.30 *et seq.*

Zero Initial Slope (of Waveform) 3.43
Zoomar 1.58, 1.95

BASIC

TELEVISION

VAN VALKENBURGH
NOOGER & NEVILLE
INC.

PARTS
1, 2 & 3
COMPLETE

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